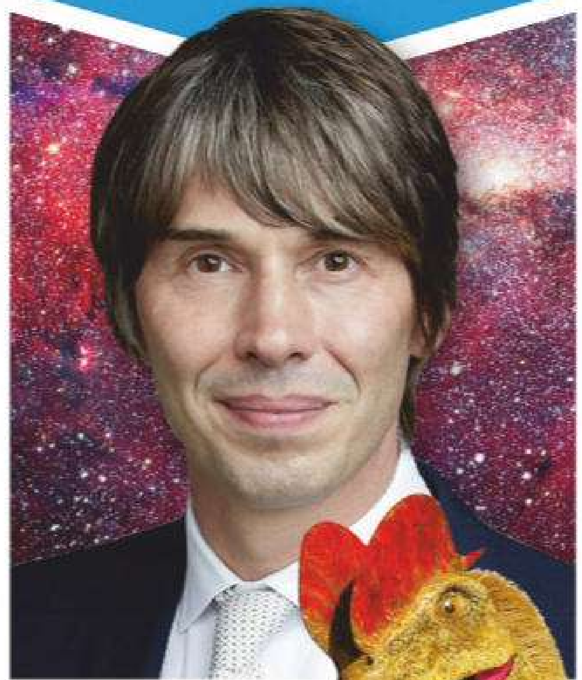
MOVIE SPECIAL EFFECTS
HOW VFX WIZARDS MAKE THE CINEMA MAGIC

PROFESSOR BRIAN COX
"WE WILL BE MARTIANS"



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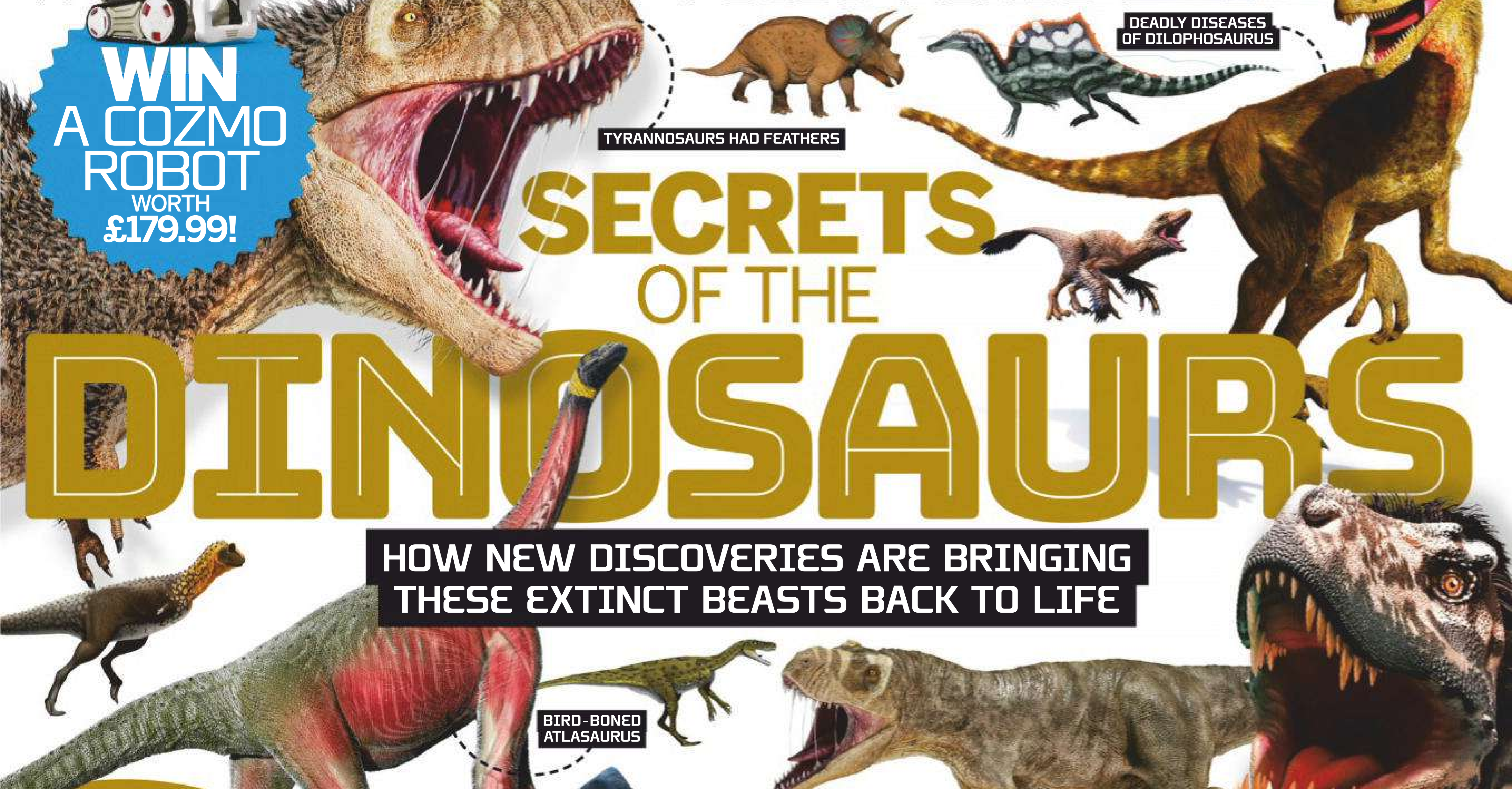
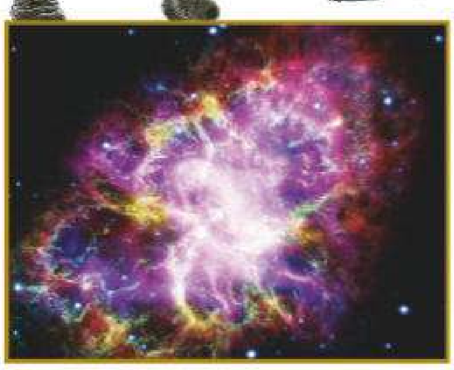


SECRETS OF THE DINOSAURS

HOW NEW DISCOVERIES ARE BRINGING THESE EXTINCT BEASTS BACK TO LIFE

HYPERSONIC AEROPLANES
GET READY FOR THE AGE OF 12,000KPH PASSENGER JETS



WHY THE UNIVERSE IS EXPANDING

LEONARDO DA VINCI'S AMAZING INVENTIONS

HOW FIGHTER PILOTS REFUEL IN MID-AIR

FUTURE
ISSUE 126

+ WHAT'S AN ATOM MADE OF? FIXING NOTRE-DAME HOW WHALES FEED MILLIONS

WELCOME

The magazine that feeds

© Chase Elliott Clark

"Dinosaurs probably all had simple developing feathers"

What the dinosaurs really looked like, page 24

Meet the team…

James
Production Editor
Leonardo da Vinci was a man whose ideas were hundreds of years ahead of his time. We take a look at his inventions on page 40.

Scott
Staff Writer
The world's grove plays a vital role, but how does each tree serve its ecosystem? Discover how trees are teeming with life on page 74.

Baljeet
Research Editor
How can an injection protect us from illness? On page 38 we see how a vaccine readies our immune system's very own army.

Duncan
Senior Art Editor
Ever wondered how movie makers create terrifying monsters and enormous explosions? Find out on page 48 as we explore movie VFX.

It's incredible how our understanding of what the dinosaurs were really like has changed in the last 20 years. Increasingly sophisticated digital reconstruction techniques, alongside the latest DNA science and improving methods of recovering prehistoric remains, means the dinosaurs are far from the scaly reptilian monsters we once thought they were. In our special feature on page 24, we've spoken to the experts on prehistoric beasts at Eofauna about their latest discoveries, showing how dinosaurs looked, moved and even acted very differently to the way we thought.

We've also spoken to visual effects creators Outpost VFX about how they bring movies to life, and to BAE/Reaction Engines, the makers of a super-fast jet engine capable of 12,000kph! Also discover what atoms are made of, how internet cables are laid across oceans, tree ecosystems and much more inside. Enjoy!

Ben Biggs Editor

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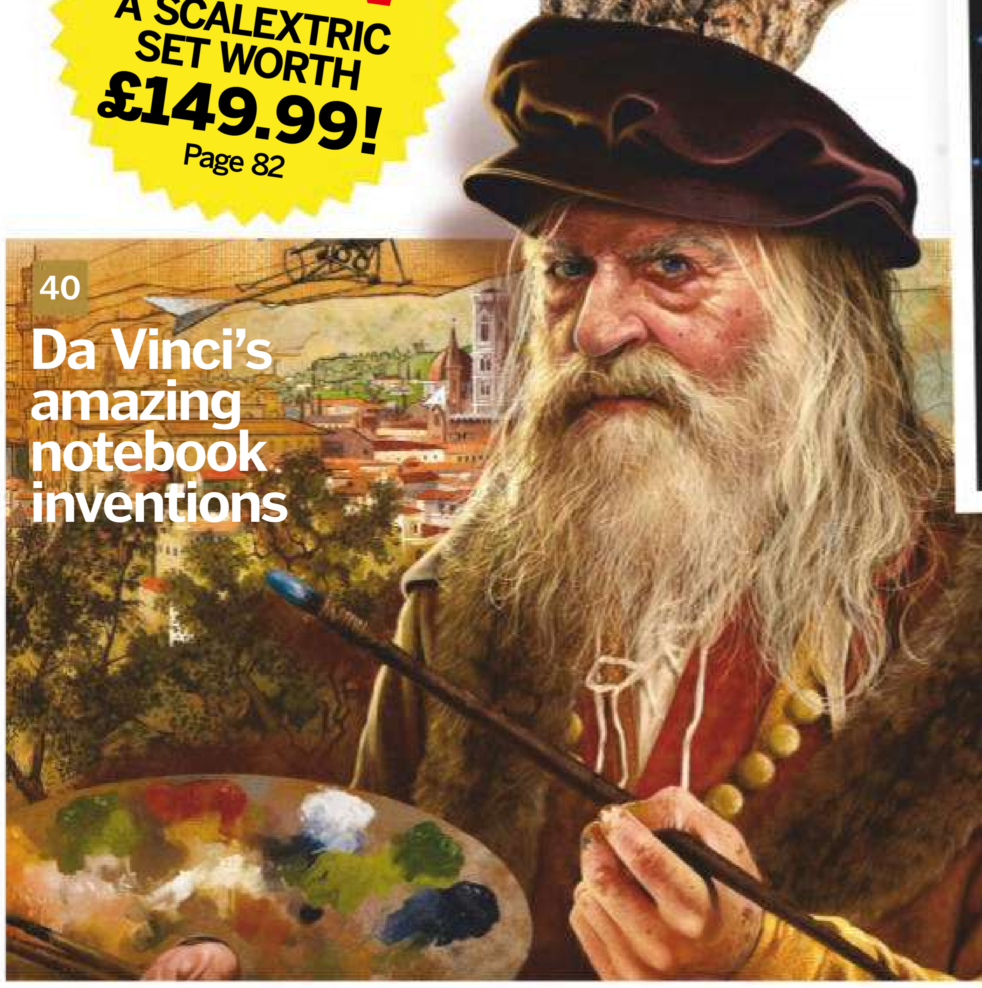

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MEET THIS ISSUE'S EXPERTS...

James Horton
Former **HIW** member James is a biochemist and biotechnologist. He is currently doing a PhD in machine learning and evolutionary theory.

Jo Stass
Writer and editor Jo is particularly interested in the natural world and learning about the latest in technological innovations.

Jodie Tyley
The former editor of **HIW** and **All About History** has tackled many topics in her career, from science fiction to science fact, and Henry VIII to honey badgers.

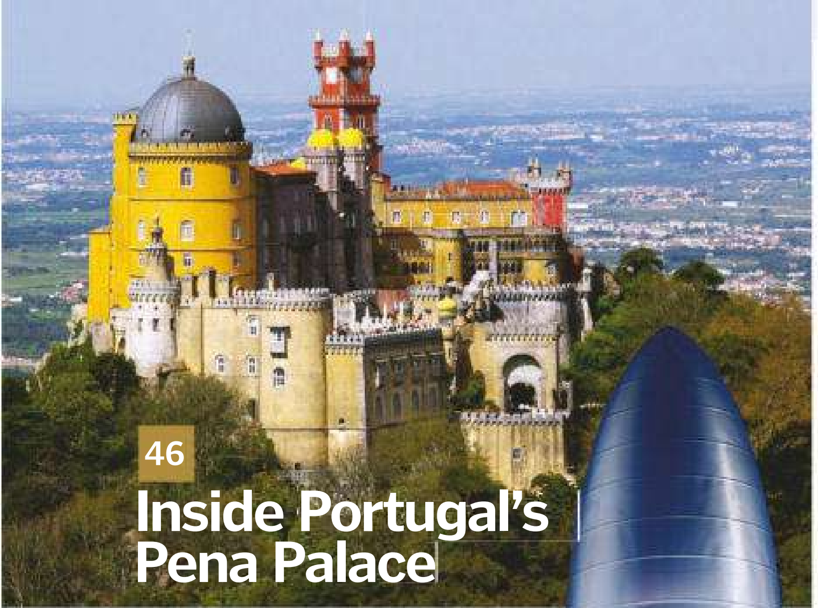
Laura Mears
Biomedical scientist Laura escaped the lab to write about science and is now working towards her PhD in computational evolution.

Stephen Ashby
Stephen is a writer and editor with video games and computer tech expertise. He is endlessly intrigued by Earth science.

Steve Wright
Steve has worked as an editor on many publications. He enjoys looking to the past, having also written for **All About History** and **History Of War**.

Philippa Grafton
As the former editor of **History Of Royals,** Phil loves to explore palaces and the tales of the royals who built them.

Tom Lean
Tom is a historian of science at the British Library, working on oral history projects. His first book, *Electronic Dreams*, was published in 2016.



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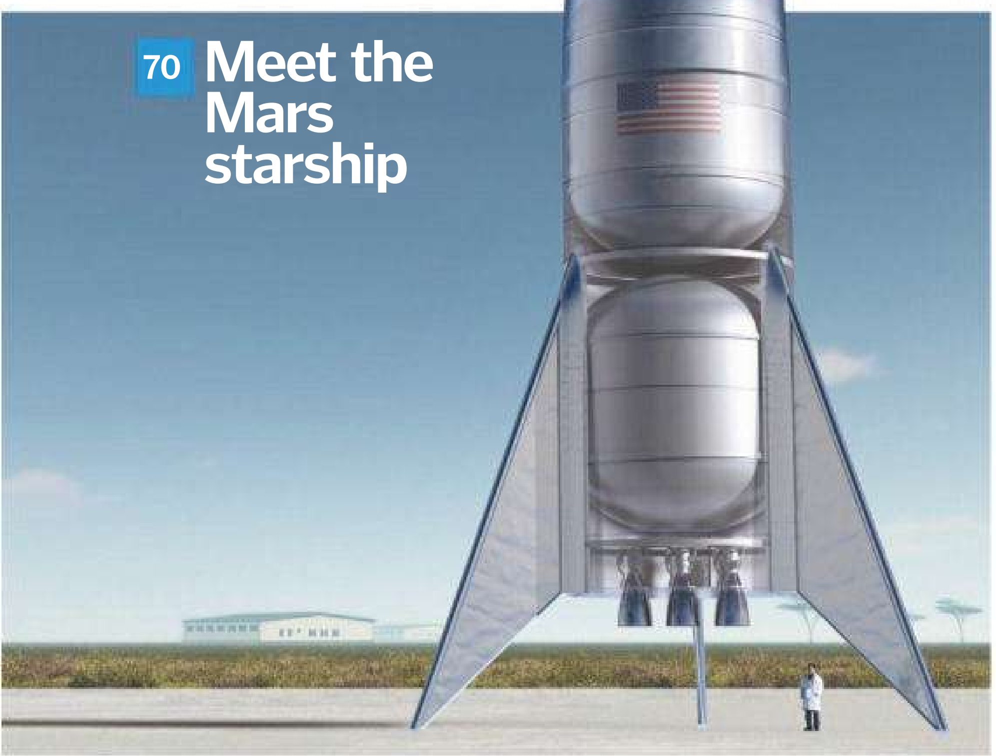

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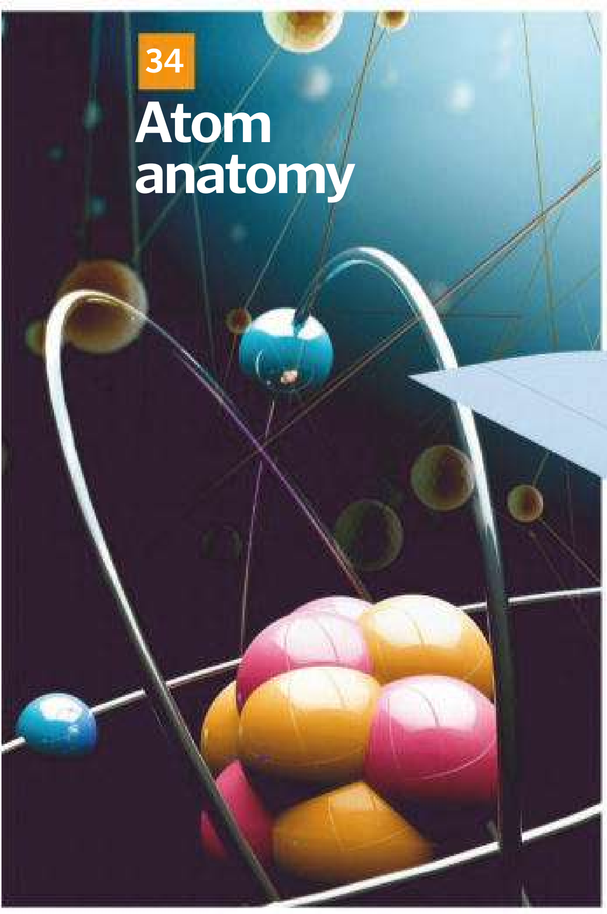

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Victoria Williams
Evolutionary biologist and science writer Vicky is fascinated by the natural world and is happiest when she's in the outdoors.

Mark Smith
Mark is a technology and multimedia specialist who has written for leading online and print publications for many years.

Amy Grisdale
Volunteer animal worker Amy has an enormous breadth of experience on animal and conservation projects. She specialises in environment topics.

Jack Parsons
A self-confessed technophile, Jack has a keen interest in gadgets and wearable tech, but loves to write about projects with much grander ambitions.

Jonny O'Callaghan
With a background in astrophysics and a love of the mysteries of the cosmos, Jonathan enjoys delving into the wonders of space.

Lee Cavendish
As resident staff writer on our sister publication **All About Space**, Lee is an avid stargazer and is fascinated by all things space-related.

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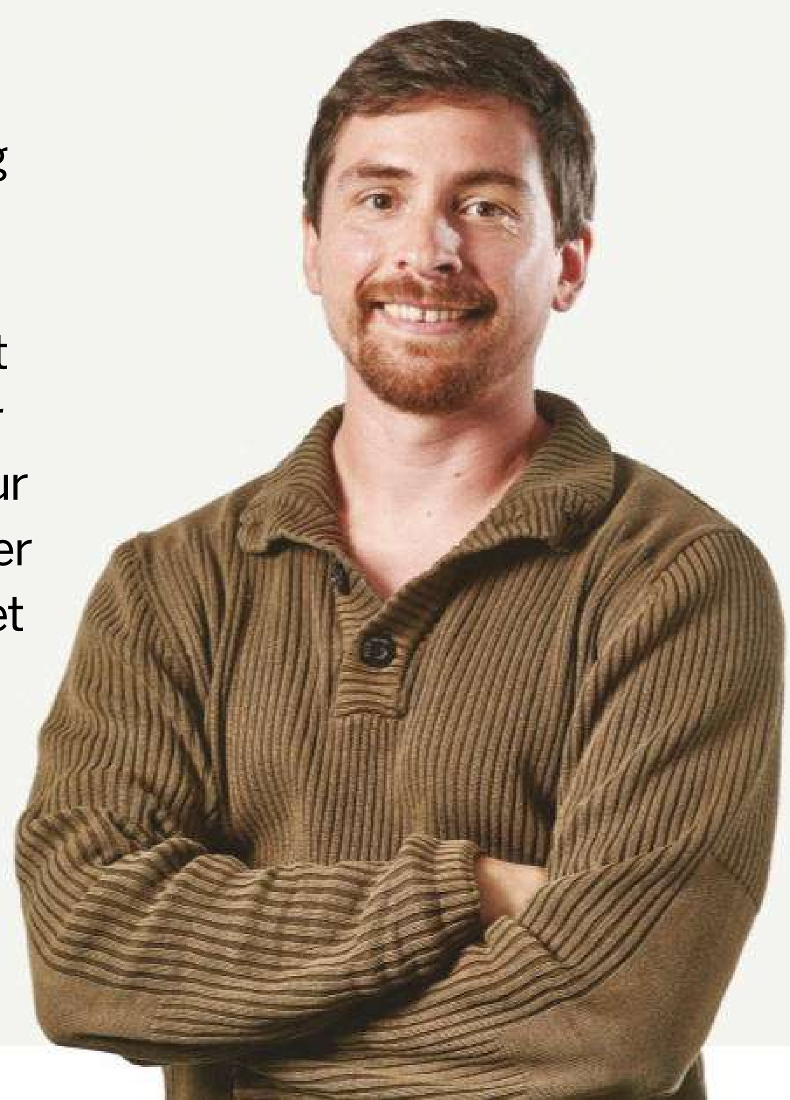
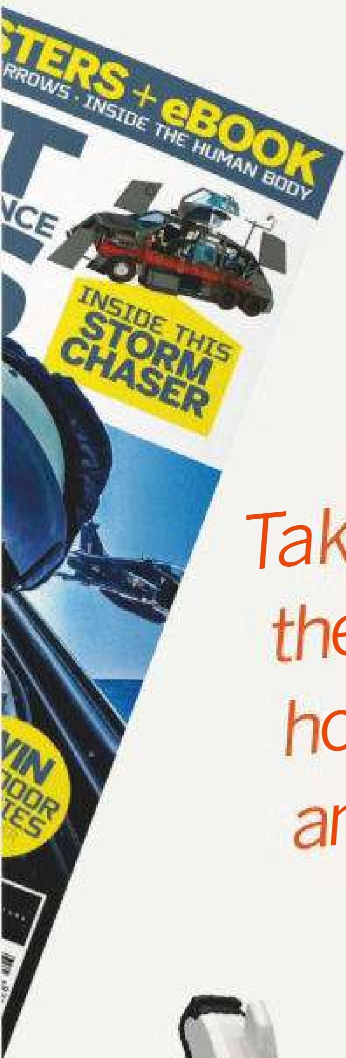
Ben Biggs, Editor





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FUTURE

Monitoring a melting glacier

A single-engine propellor plane flies over Sheridan Glacier in Alaska, showing its descent from the mountains into the sea. The purpose of this and other flights by NASA-funded researchers is to measure and monitor glaciers in this region, as part of a bigger campaign called Operation IceBridge that monitors Earth's ice. Around five per cent of Alaska is covered by glaciers, which have been steadily melting, depositing meltwater into the sea and contributing to the increase in sea levels.


©NASA

Playing with a rainbow

A child puts her hand into the fine spray that's creating a rainbow effect, in one of environmental artist Olafur Eliasson's exhibits at the Tate Modern in London. The rainbow projection is being caused by the fine droplets of the water spray refracting the white light from the spotlight, effectively splitting the beam into its component colours. The rainbow that appears is enhanced by its projection into a darkened room.

© OLAFUR ELIASSON

1,100-degree Celsius jet of molten rock

This ten-metre fountain of lava gushes out of a fissure in the rock, south of Pu'u Kahaualea in Hawaii. The volcanic cone of Pu'u O'o had been erupting almost continuously from 1983 up until 2018, when the crater floor collapsed and the magma drained away to another part of the island. The 35 years of volcanic activity from Pu'u O'o destroyed nearly 200 buildings, miles of highway, several historic sites, and completely covered several beaches with a thick layer of lava.

GLOBAL EYE

Showcasing the incredible world we live in

IN ASSOCIATION WITH LIVESCIENCE

With over 14 million global monthly users, **Live Science** makes every day a little more interesting by illuminating the fascinating world around us. For the science geek in everyone, **Live Science** breaks down the stories behind the most interesting news and photos on the internet.

A subterranean 'blob' of rock may be the explanation for earthquakes in Asia

PLANET EARTH

Rock 'blob' triggers hundreds of earthquakes

Words by **Brandon Specktor**

The Hindu Kush mountain range, which stretches about 800 kilometres along the border of Afghanistan and Pakistan, shudders with more than 100 earthquakes at a magnitude of 4.0 or greater every year. The area is one of the most seismically active spots in the world, especially for intermediate-depth quakes (tremors forming between 70 and 300 kilometres below the planet's surface). And yet scientists aren't sure why. The mountains don't sit on a major fault line, where high earthquake activity is expected, and the region is many kilometres away from the slow-motion crash zone where the Eurasian and Indian tectonic plates are steadily colliding.

So what's the deal with this earthquake epidemic? According to a recent study, the Hindu Kush mountains may owe their incredible seismic reputation to a long 'blob' of rock that's slowly dripping away from the range's subterranean underbelly and into the hot, viscous mantle below.

Like a lone water droplet dripping from the edge of a tap, the 150-kilometre-deep blob of mountain may be pulling away from the continental crust at a rate as fast as ten centimetres per year – and it is this subterranean stress that could be triggering the frequent earthquakes in the region, the authors of the new study wrote.

The researchers discovered the troublesome blob after collecting several years' worth of earthquake observations near the Hindu Kush mountains. They saw that the earthquakes formed a pattern, creating what looked like a 'round patch' of seismic activity on the planet's surface, study co-author Rebecca Bendick, a geophysicist at the University of Montana in Missoula, told the website *Eos.org*. Those earthquakes also formed along a clear vertical axis, beginning between 160-230 kilometres below the continent, and were most common deeper down, where the solid continental crust meets the hot, viscous upper mantle. Here, the researchers wrote, is where the slowly stretching blob is strained the most.

If accurate, these results may be evidence that geophysical forces beyond just the subduction of tectonic plates can send earthquakes rattling through the planet. As it was best put in 1958: beware of the blob.

DNA data suggests dinosaurs also slept with bed bugs

ANIMALS

We've had bedbugs for 115 million years

Words by **Brandon Specktor**

Should you ever have to endure the nightmare of a bedbug infestation, take solace that, perhaps, a pterodactyl once had to deal with the same annoyance. A recent study in the journal *Current Biology* has found that bedbugs have existed in one form or another for 115 million years, putting the pernicious parasites on Earth at the same time as the dinosaurs.

A team of researchers spent 15 years collecting wild bedbugs from around the world and studying specimens in museum collections. The team compared the DNA of these modern bugs to see how different species diverged in the past and how often new species arose to pester humans and other potential hosts. "The first big surprise we found was that bedbugs are much older than bats, which everyone assumed to be their first host," lead study author Steffen Roth, from the University Museum of Bergen in Norway, said in a statement. Roth and his colleagues found that bedbugs beat bats to the planet by some 50 million years.

TECH

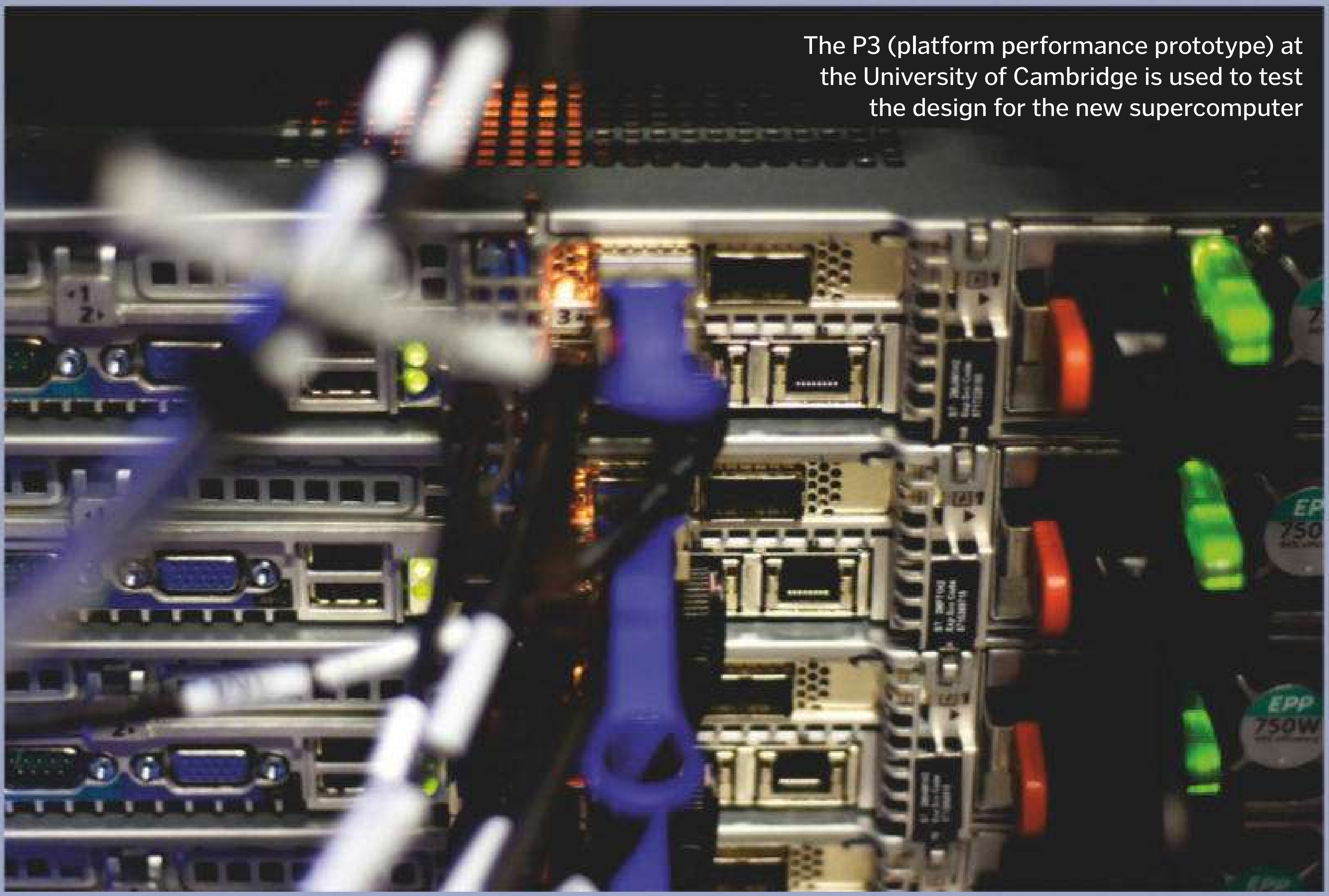
New supercomputer's speed equal to 250 million laptops

Words by **Mindy Weisberger**

The fastest supercomputer in the world will soon be outpaced by a newer, swifter rival. Scientists recently completed the engineering design for the first of two paired supercomputers called the Science Data Processor (SDP). Together these supercomputers will manage vast quantities of data that will be collected by the Square Kilometre Array (SKA), a network of radio telescopes located in Perth, Australia, and Cape Town, South Africa, SKA representatives said in a statement.

An international team of researchers representing 11 countries collaborated for five years to produce the hardware, software and algorithms to drive the first of the two supercomputers, according to the statement. When completed, the powerhouse processors will wrangle 600 petabytes (one petabyte is equal to 1 million gigabytes) of data per year, or "enough to fill more than a million average laptops," said Maurizio Miccolis, an SDP project manager based in the UK.

How fast will the new supercomputer be? Processing speed is measured in floating-point operations per second, or flops. A powerful supercomputer's performance is expressed in petaflops: 1 quadrillion calculations per second. By comparison, the speed of most personal computers is measured in gigaflops: 1 billion calculations per second. Researchers estimate that SDP will operate at 250 petaflops, or 250 quadrillion calculations in an instant, making it 25 per cent faster than IBM's Summit, "the current fastest supercomputer in the world," Miccolis said.



The P3 (platform performance prototype) at the University of Cambridge is used to test the design for the new supercomputer

SPACE

NASA spots spacecraft grave

Words by **Elizabeth Howell**

A sharp-eyed NASA spacecraft spotted the probable remains of an Israeli spacecraft that crash-landed on the Moon in April. New lunar images show what appears to be the final resting place of the Beresheet lander, a spacecraft managed by nonprofit organisation SpaceIL.

Beresheet's impact site appears as a "white impact halo" in the new image from the Lunar Reconnaissance Orbiter (LRO), NASA officials said. "The cameras captured a smudge, about ten metres wide, indicating the point of impact. The dark tone suggests a surface roughened by the hard landing, which is less reflective than a clean, smooth surface," NASA officials said. "The light halo around the smudge could have formed from gas associated with the impact or from fine soil particles blown outward during Beresheet's descent, which smoothed out the soil around the landing site, making it highly reflective."

The mission of Beresheet, the first private lunar lander, came to a sudden end on 11 April during its descent to the Moon's surface. LRO's orbit first brought it over the impact site on 22 April, and the orbiter captured the image using its black-and-white, narrow-angle cameras. NASA found the site thanks to radio tracking of Beresheet's descent, which pinpointed the landing site to within a few kilometres.

Technicians compared new images to 11 'before' images of the area and found only one feature that could have been made by Beresheet. They also compared the site to craters made by other craft on the lunar surface, like GRAIL, LADEE and Ranger.

NASA isn't done with its Beresheet observations yet. Small mirrors were mounted on the top of it, so NASA is trying to bounce laser pulses from LRO onto the mirrors. It's not clear yet if the retroreflector survived the crash.

NASA's Lunar Reconnaissance Orbiter spotted the crash site of SpaceIL's Beresheet spacecraft, which failed during a Moon landing on 11 April 2019

HEALTH

Ultraprocessed foods increase weight gain

Words by **Rachael Rettner**

Filling your plate with ultraprocessed foods really does appear to lead people to eat more and gain weight, according to a recent study. Published in the journal *Cell Metabolism*, the study involved 20 healthy volunteers who spent about a month in a laboratory at the National Institutes of Health's (NIH) Clinical Center in Bethesda, Maryland, where all of their meals were prepared for them.

Participants were randomly assigned to a diet of either ultraprocessed or minimally processed foods for two weeks, after which they were switched to the opposite diet for another two weeks. Importantly, meals for both groups had about the same amount of calories, sugars, fibre, fat and carbohydrates; participants could eat as much as they wanted. The researchers found that, when people were given the ultraprocessed diet, they ate about 500 calories more per day than they did when they were on the unprocessed diet. What's more, participants gained about 0.9 kilograms while they were on the ultraprocessed diet; they lost about 0.9 kilograms while on the unprocessed diet.

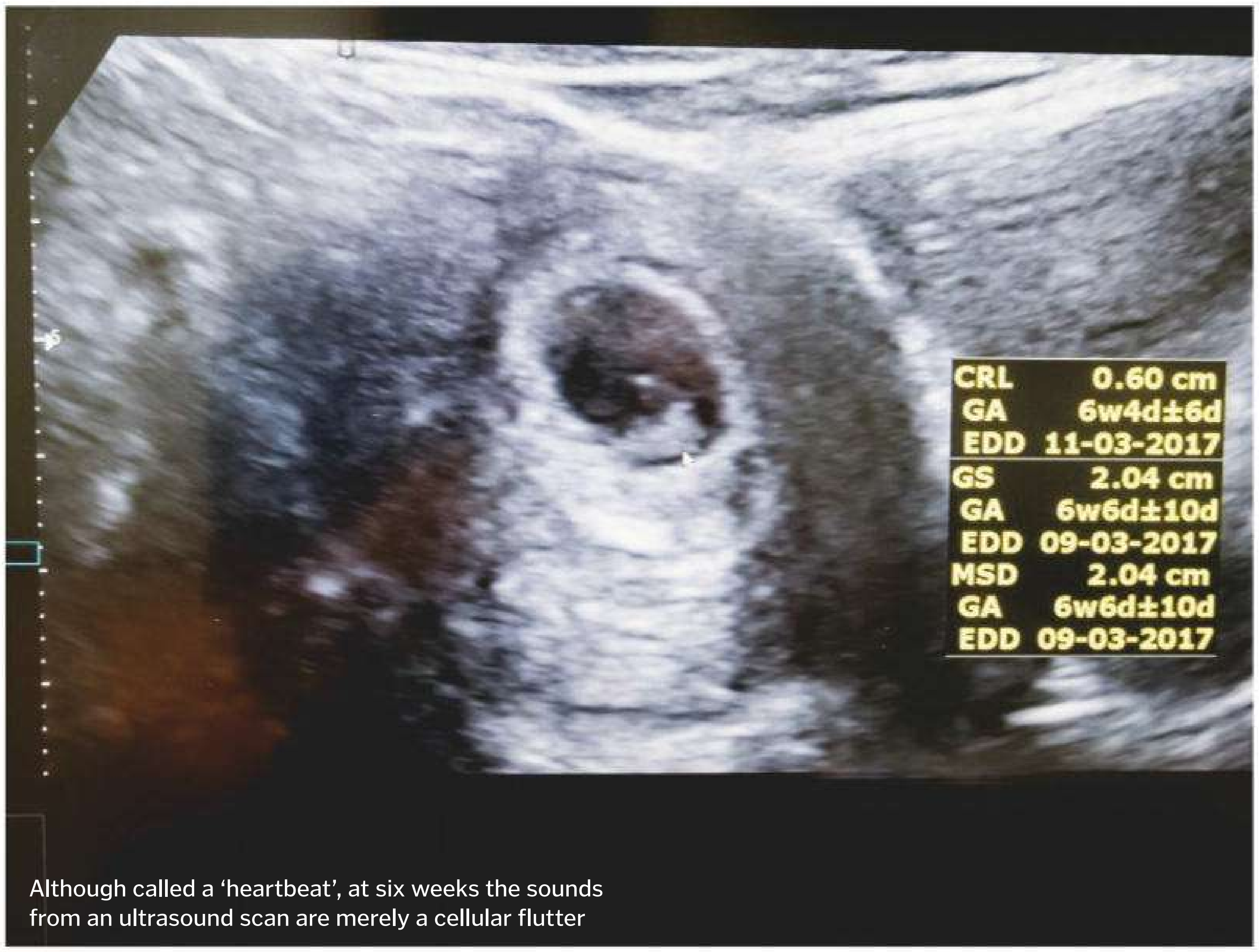
Although the new study was small, "results from this tightly controlled experiment showed a clear and consistent difference between the two diets," study lead author Kevin Hall, a senior investigator at NIH's National Institute of Diabetes and Digestive and Kidney Diseases, said in a statement.

HEALTH

How a 'foetal heartbeat' is heard at six weeks

Words by **Rachael Rettner**

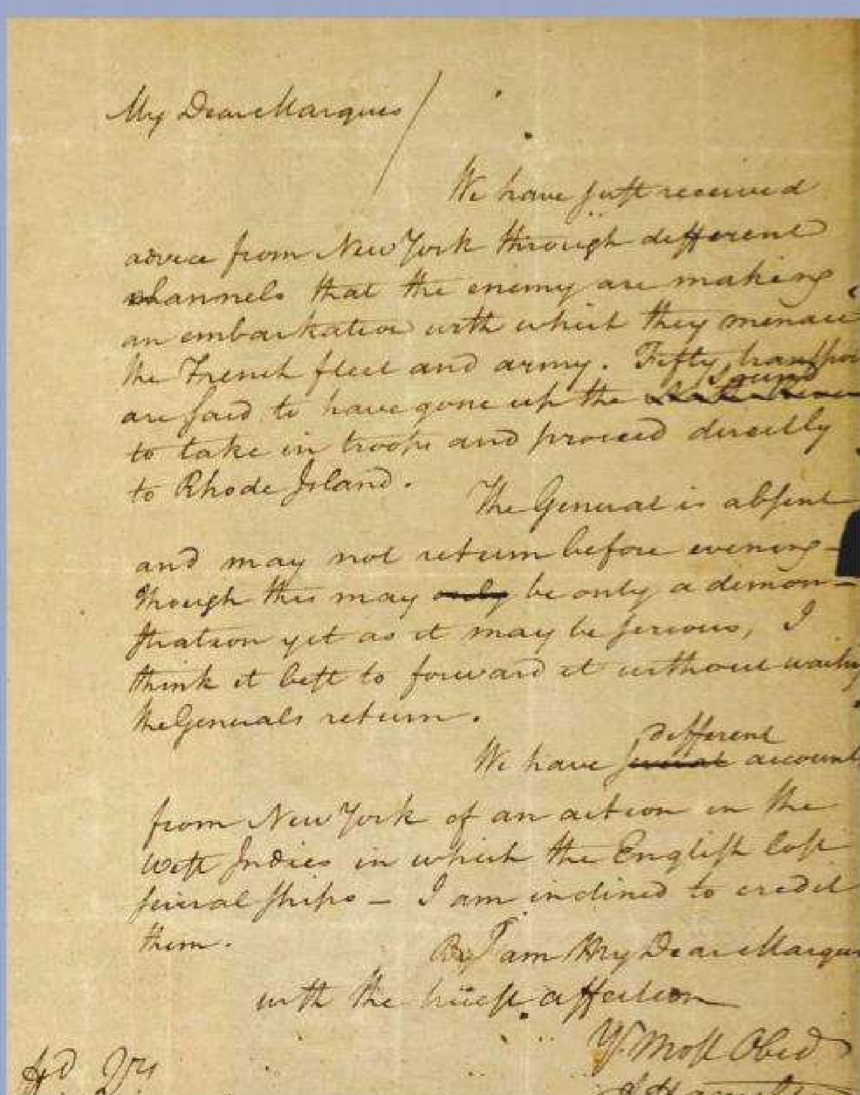
What exactly do we mean when we talk about a 'foetal heartbeat' at six weeks of pregnancy? Although some people might picture a heart-shaped organ beating inside a foetus, this is not the case. Rather, at six weeks of pregnancy, an ultrasound can detect "a little flutter in the area that will become the future heart of the baby," according to Dr Saima Aftab, medical director of the Fetal Care Center at Nicklaus Children's Hospital in Miami.



Although called a 'heartbeat', at six weeks the sounds from an ultrasound scan are merely a cellular flutter

This flutter happens because the group of cells that will become the future 'pacemaker' of the heart gain the capacity to fire electrical signals, she said. But the heart is far from fully formed at this stage, and the 'beat' isn't audible; if doctors put a stethoscope up to a woman's belly this early on in her pregnancy, they would not hear a heartbeat. It's been only in the last few decades that doctors have even been able to detect this flutter at six weeks, thanks to the use of more sophisticated ultrasound technologies. Previously, the technology wasn't advanced enough to detect the flutter that early on.

The heart still has a lot of development to undergo before it is fully formed. The entire first trimester of pregnancy is a time of 'organogenesis' or the formation of organs.


My Dear Marquis /

We have just received advice from New York through different channels that the enemy are making an embarkation with which they menace the French fleet and army. Fifty transports are said to have gone up the Sound to take in troops and proceed directly to Rhode Island. The General is absent and may not return before evening. Though this may ~~only~~ be only a demonstration yet as it may be serious, I think it best to forward it without waiting the General's return.

We have ~~[illegible]~~ different accounts from New York of an action in the West Indies in which the English lost several ships — I am inclined to credit them.

Be I am My Dear Marquis with the truest affection

Yr Most Obed

A Hamilton

Hd. Qrs

Stolen more than six decades ago, a letter by Alexander Hamilton to the Marquis de Lafayette in 1780 has finally resurfaced

HISTORY

US founding father's letter resurfaces after 60 years

Words by **Brandon Specktor**

History had its eyes on Alexander Hamilton – and now, federal agents have their eyes on one of the Founding Father's long-lost letters, penned in 1780 and stolen from the Massachusetts Archives more than six decades ago. According to the *Associated Press (AP)*, the letter from Hamilton to his revolutionary comrade the Marquis de Lafayette was stolen from the archives by an employee sometime between 1937 and 1945.

It resurfaced for the first time in November 2018, when a South Carolina family submitted the letter to an auction house in Alexandria, Virginia, hoping to sell the document. The letter was valued at $25,000, the website *MassLive.com* reported, before auction house researchers discovered the item's dubious provenance and promptly contacted the FBI.

In the newly resurfaced letter, dated 21 July 1780, Hamilton alerts his "Dear Marquis" to news of British troop movements in the midst of the American War of Independence. At that time, the British surrender and the war's end were still several years away. Hamilton was serving as General Washington's aide-de-camp, his right-hand man.

Have we reached a tipping point on carbon dioxide emissions?

PLANET EARTH

Carbon dioxide soars to record-breaking levels

Words by **Yasemin Saplakoglu**

There is more carbon dioxide (CO_2) in the atmosphere than there has been for 800,000 years – since before our species evolved. On 11 May 2019 the levels of the greenhouse gas reached 415 parts per million (ppm), as measured by the National Oceanic and Atmospheric Administration's Mauna Loa Observatory in Hawaii.

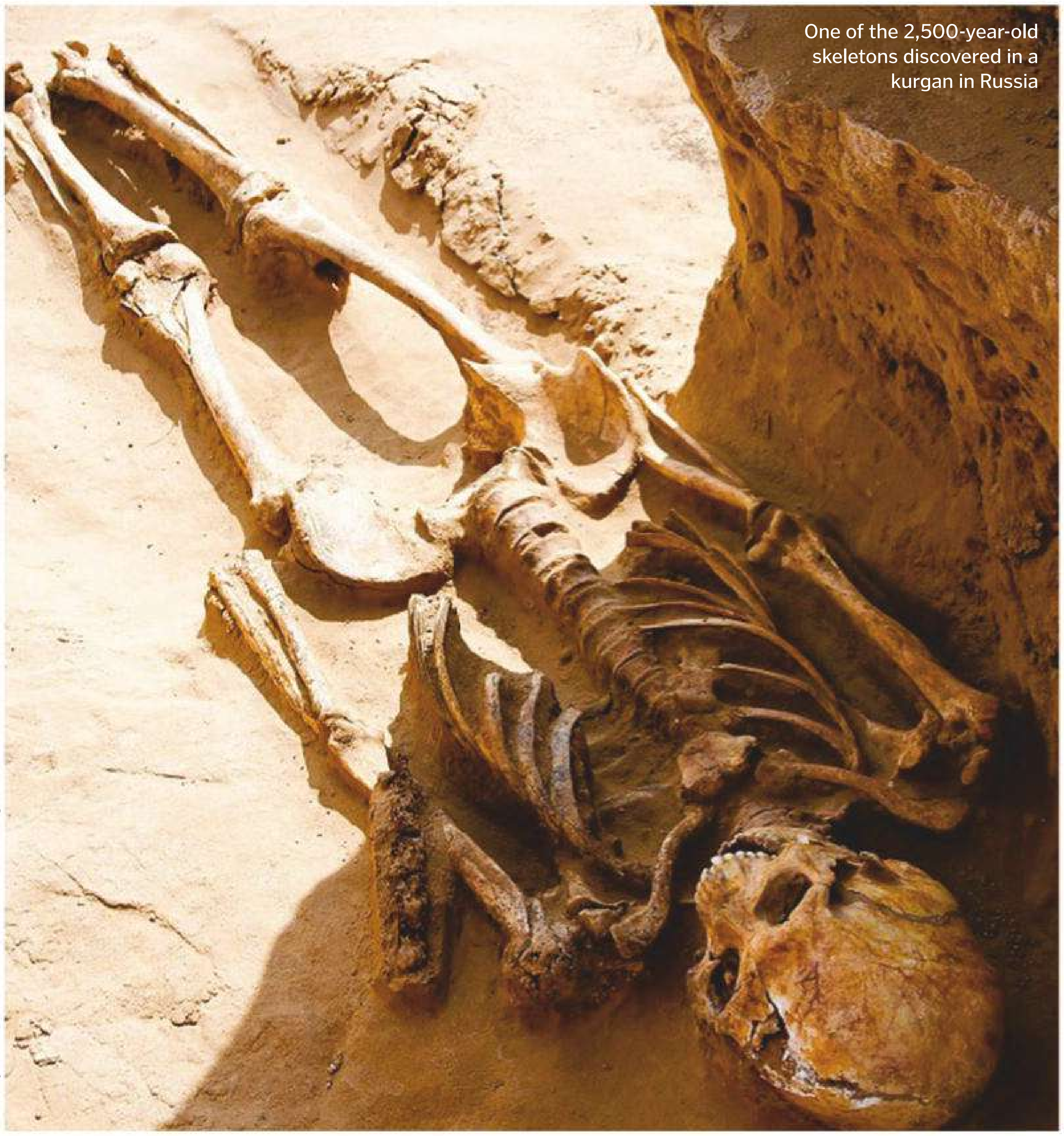
Scientists at the observatory have been measuring atmospheric carbon dioxide levels since 1958. But because of other kinds of analysis, such as those done on ancient air bubbles trapped in ice cores, they have data on levels reaching back 800,000 years. During the ice ages carbon dioxide levels in the atmosphere were around 200 ppm. And during the interglacial periods – the planet is currently in an interglacial period – levels are around 280 ppm, according to NASA.

Every year, the Earth sees about 3 ppm more carbon dioxide in the air, said Michael Mann, a distinguished professor of meteorology at Pennsylvania State University. "If you do the math, well, it's pretty sobering," he said. "We'll cross 450 ppm in just over a decade." The subsequent warming is already causing changes to the planet – shrinking glaciers, bleaching coral reefs and intensifying heat waves and storms, among other impacts. And carbon dioxide levels higher than 450 ppm "are likely to lock in dangerous and irreversible changes in our climate," Mann told **Live Science**.

"We keep breaking records, but what makes the current levels of CO_2 in the atmosphere most troubling is that we are now well into the 'danger zone' where large tipping points in the Earth's climate could be crossed," said Jonathan Overpeck of the School for Environment and Sustainability at the University of Michigan.

The last time atmospheric carbon dioxide levels were this high, way before *Homo sapiens* walked the planet, the Antarctic ice sheet was much smaller and sea levels were up to 20 metres higher than they are today, Overpeck told **Live Science**. "Thus, we could soon be at the point where comparable reductions in ice sheet size, and corresponding increases in sea level, are both inevitable and irreversible over the next few centuries." Smaller ice sheets, in turn, might reduce the reflectivity of the planet and potentially accelerate the warming even more, he added.

> *"What makes the current levels of CO_2 in the atmosphere most troubling is that we are now well into the 'danger zone'"*



One of the 2,500-year-old skeletons discovered in a kurgan in Russia

HISTORY

2,500-year-old tribe's remains found in Russia

Words by **Owen Jarus**

A farmer in Russia has uncovered the remains of three elite members of a nomadic tribe from 2,500 years ago. A horse's skull and harness were found buried alongside one of the individuals. Three 2,500-year-old burials of elite members of a group known as the Sarmatians have been discovered within a kurgan (a large mound) in a village called Nikolskoye in Russia, northwest of the Caspian Sea.

The three skeletons were discovered inside the remains of wooden coffins within the kurgan. Though the kurgan had been robbed in ancient times, many artefacts, such as weapons, gold jewellery and household items like a bronze cauldron were discovered near the coffins, according to two Russian language statements released by the Astrakhan regional government. The three burials date back to a time when the Sarmatians flourished in the region. This nomadic group thrived in southern Russia, before moving into eastern and central Europe while fighting wars against other ancient peoples like the Scythians, Romans and Goths.

Excavation of the kurgan and analysis of the remains is ongoing. They have yet to determine how the individuals died or their gender and age. Kurgans have frequently popped up throughout Russia and neighbouring countries over the last century; they often contain the burials of elite members of ancient groups. Archaeological remains from the newly found kurgan are being taken to the Astrakhan State Museum, the statements said.

STRANGE NEWS

Crack a 230-year-old secret code to win €2,000

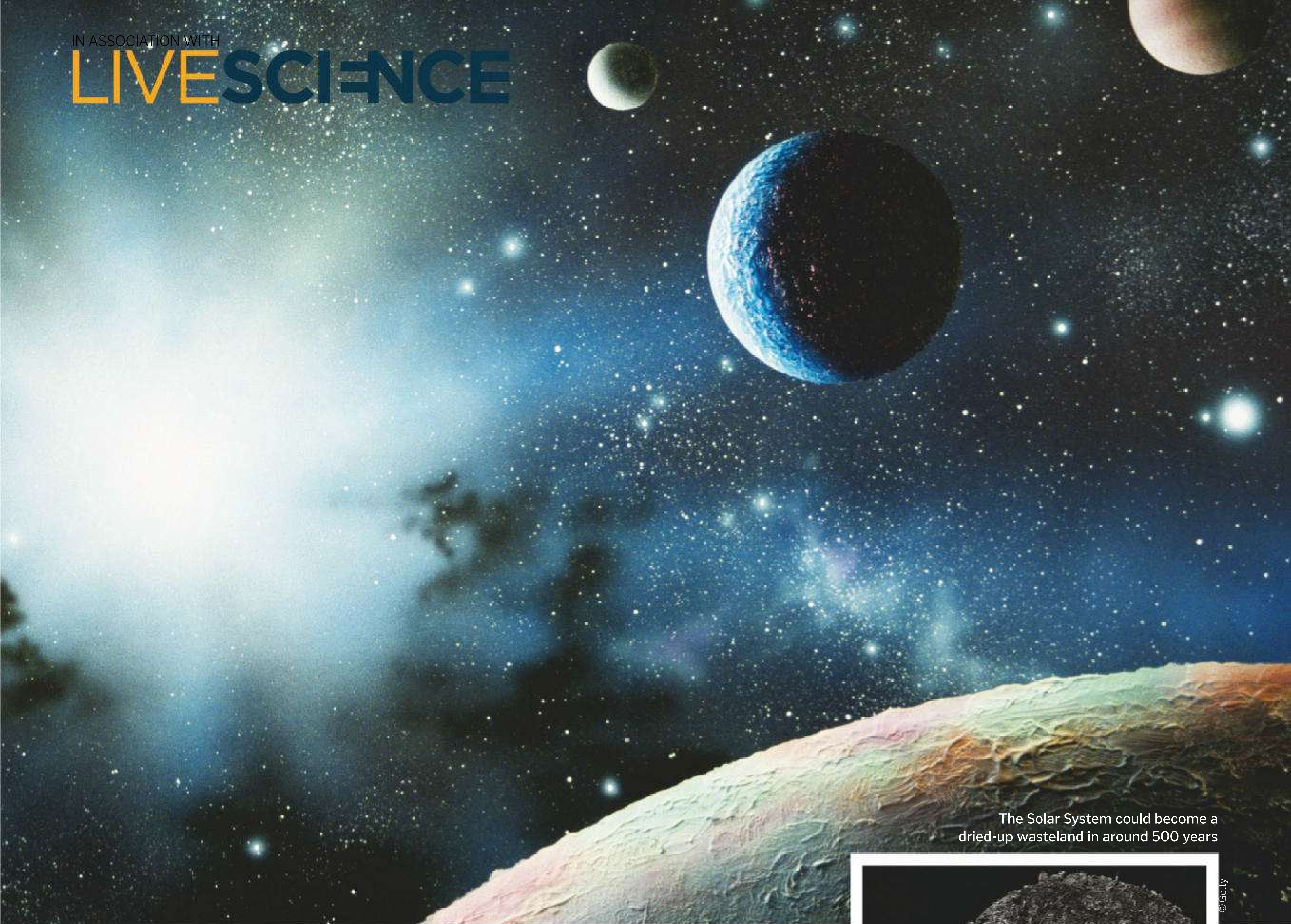
Words by **Brandon Specktor**

A village in northwest France has offered a reward of €2,000 (£1,750) for anyone who can decrypt a series of letters and symbols chiselled into a boulder nearby. Located on a beach near the village of Plougastel-Daoulas, Brittany, and only visible at low tide, the stone was rediscovered three or four years ago but is believed to have been inscribed more than 200 years before.

According to the French news site AFP, one side of the rock is completely adorned in jumbled capital letters, symbols including a picture of a sailboat and a heart and the dates 1786 and 1787. The mysterious inscription has baffled visiting academics and amateur codebreakers for years. Now the town has opened the puzzle to the public, giving people until 30 November to submit their guesses. A jury will then decide which interpretation is the most plausible and award the €2,000 prize after that, AFP reported.

According to AFP, the legible parts of the inscription intriguingly read, "ROC AR B … DRE AR GRIO SE EVELOH AR VIRIONES BAOAVEL … R I OBBIIE: BRISBVILAR … FROIK … AL."

A French town is offering a cash prize to solve a rock carving code that's 230 years old



The Solar System could become a dried-up wasteland in around 500 years

© Getty

SPACE

Space mining could ruin our Solar System

Words by **Brandon Specktor**

While heads of state bicker over protecting Earth's most vulnerable places from the ravages of industry, a new study suggests that maybe it's not too early to start protecting other worlds from human exploitation, too. The study, published on 16 April in the journal *Acta Astronautica*, makes a case for designating 85 per cent of our Solar System a protected 'wilderness' akin to Earth's national parks, leaving just one-eighth of eligible planets, moons and asteroids free to be mined or developed by human interests.

If the growth of a space economy is anything like the exponential growth of terrestrial economies since the Industrial Revolution began roughly two centuries ago, the study authors wrote, then humans could deplete the Solar System of all of its water, iron and other mineable resources in a matter of centuries, potentially leaving the Solar System a dried-up wasteland in as little as 500 years. Limiting the exploitation of resources on other worlds now, before the space economy kicks off in earnest, is crucial to avoiding what the researchers call a "crisis of potentially catastrophic proportions."

Limiting galactic consumption to one-eighth of the available resources might sound like a bad deal on its face, but space is a big place and even a small fraction of our Solar System's bounty could set humanity up for generations. "One-eighth of the iron in the asteroid belt is more than a million times greater than all of the Earth's currently estimated iron ore reserves," the authors wrote, "and it may well suffice for centuries." If Earthlings show a comparable level of industriousness when mining the resources on nearby planets, moons and asteroids, we'd reach the hypothetical one-eighth point after 400 years, the authors calculated.

If production continued to double every 20 years after that, all of the Solar System's resources would be depleted just 60 years later. That would give humans 60 years to transition from a space-resource-based economy to something completely different – a challenging prospect, given the lacklustre response to current environmental crises like population growth and climate change on Earth, the researchers wrote.

AIRFIX QUICKBUILD

1	9.12 m	11.23 m
22.48 m²	2,182 kg	571 km/h
925 km	771 m/m	9,723 m

1 x Rolls Royce Merlin II V12

1	9.83 m	11.28 m
21.83 m²	3,465 kg	703 km/h
2,755 km	978 m/m	12,800 m

1 × Packard V-1650-7 liquid-cooled supercharged V-12

D-Day Aircraft

FIGHTER PLANES OF THE NORMANDY INVASION

"You are about to embark upon the Great Crusade, toward which we have striven these many months. The eyes of the world are upon you..."
—Eisenhower, Letter to Allied Forces

Operation Overlord, commonly known as D-Day, was launched on 6 June 1944 with the Normandy landings. A 1,200-plane airborne assault preceded an amphibious assault involving more than 5,000 vessels. Nearly 160,000 troops crossed the English Channel on 6 June, and more than two million Allied troops were in France by the end of August.

P-51D Mustangs™ and Supermarine Spitfires were among the D-Day aircraft which provided air cover for the massive invasion, strafing strongholds and fighting off German bombers. As recreated on our Quickbuild models, the allies painted the plane's wings with stripes to ensure the Allied aircraft were not targeted by friendly-fire in all the chaos of war. This was kept secret and only revealed to the troops who would take part just days ahead of the first waves.

You can you create your very own fighters of the RAF at home with an Airfix QuickBuild kit. QuickBuild kits allow you to recreate a wide variety of iconic aircraft, tanks and cars into brilliant scale models. No paint or glue is required, the push together brick system results in a realistic, scale model that is compatible with other plastic brick brands.

- ***Compatible with other plastic brick brands***
- ***Features a self-adhesive sticker sheet for authentic decoration***
- ***Includes a stand to show off your handy work.***

WISH LIST

The latest ECO-FRIENDLY tech

© click & grow llc

The Smart Garden 3

■ Price: **£95 (approx $110)**
clickandgrow.com

Growing your own herbs and vegetables is a great way to cut down on plastic packaging and reduce your carbon footprint. However, in urbanised areas access to a garden can be limited – but not with the Smart Garden 3. Using 'smart soil', water is evenly distributed within each seed-hosting plant pod, free of pesticides, fungicides and hormones. From lavender to lettuce, seedlings can be germinated under a built-in, low-energy LED light, consuming only eight watts of power.

© Nest Labs

Nest

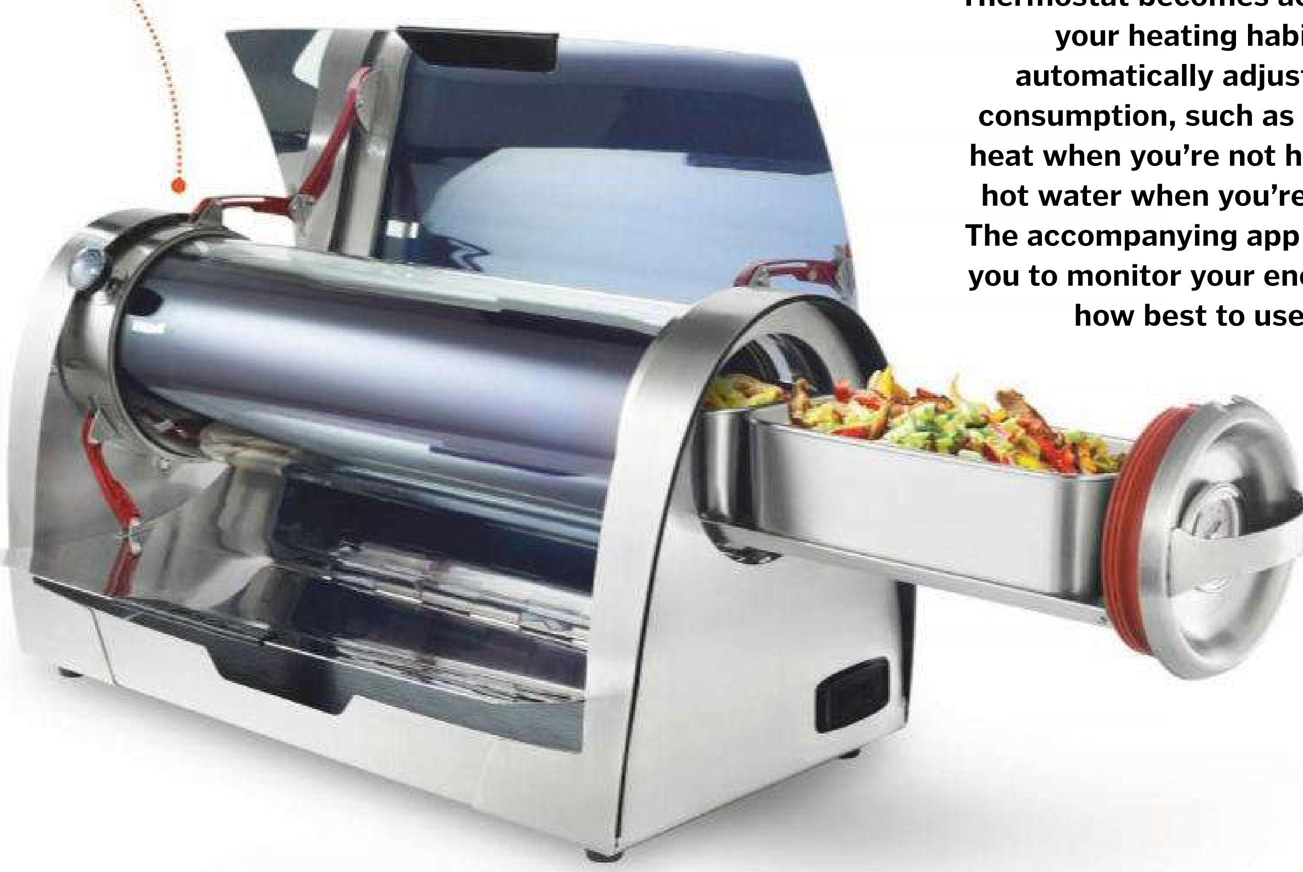
■ Price: **£219 / $249**
nest.com

Saving on electricity is not only good for your bank balance but can drastically lower your carbon footprint. The Nest Learning Thermostat becomes accustomed to your heating habits and automatically adjusts energy consumption, such as shutting off heat when you're not home and the hot water when you're on holiday. The accompanying app also enables you to monitor your energy use and how best to use less.

GoSun Grill®

■ Price: **£550 / $699**
gosun.co

The GoSun Grill uses the power of the Sun to cook your meals during a day at the beach or relaxing in the garden. Filling the removable food tray, this solar-powered oven claims to be able to bake, boil and steam enough food for eight people. The GoSun uses its reflective panels and a glass chamber to cook meals even on overcast days.



© GoSun

stojo

■ Price: £14.99 / $19.99
stojo.co

Ditching single-use coffee cups has now been made easier with this collapsible cup: this cup can hold around 470 millilitres of liquid and can flatten down into a compact disk for easy storage in a bag or pocket. BPA safe and microwave safe, stojo is the perfect way to enjoy your morning coffee on the go without throwing away environmentally harmful plastics.

© Stojo

Drumi

■ Price: $349 (approx £275)
yirego.com

Portable and pedal-powered, Yirego Drumi is the answer to low-energy laundry. Perfect for cleaning a small load of clothes, this manually powered washing machine can hold two kilograms of laundry. Without a single volt of electricity used, the Drumi is a great way to lower your carbon footprint. Using the removable spinning drum, it promises clean clothes in five to ten minutes.

© Yirego Corp

© Final Co. LLC

FinalStraw 2.0

■ Price: $29.50 (approx £25)
finalstraw.com

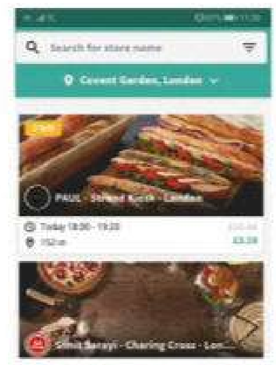
Single-use straws can wreak havoc on the world's oceans, and with a growing movement seeking their eradication, FinalStraw has introduced the second instalment of their collapsible metal straw. Smaller than its predecessor, the FinalStraw 2.0 folds into a compact case roughly eight centimetres tall and equipped to hang neatly on any keychain.

APPS & GAMES

Too Good To Go

■ Developer: **Too Good To Go**
■ Price: **Free / Google Play / App Store**

In collaboration with local food vendors and restaurants, this app helps reduce global food waste by providing a way to purchase unsold food otherwise destined for the bin.



My Little Plastic Footprint

■ Developer: **Plastic Soup Foundation**
■ Price: **Free / Google Play / App Store**

Offering a wealth of information about the world's plastic problem, this app also enables users to make pledges to reduce their plastic consumption with other users and support initiatives.

Ethical Barcode

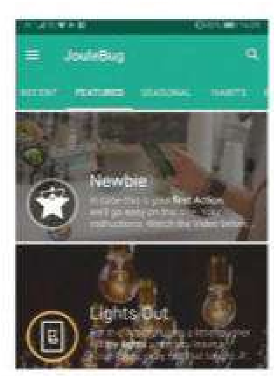
■ Developer: **david hamp-gonsalves**
■ Price: **Free / Google Play / App Store**

Stay informed about where your groceries come from, the manufacturer's ethics and environmental impact with a unique rating, simply by scanning the barcode on a product.

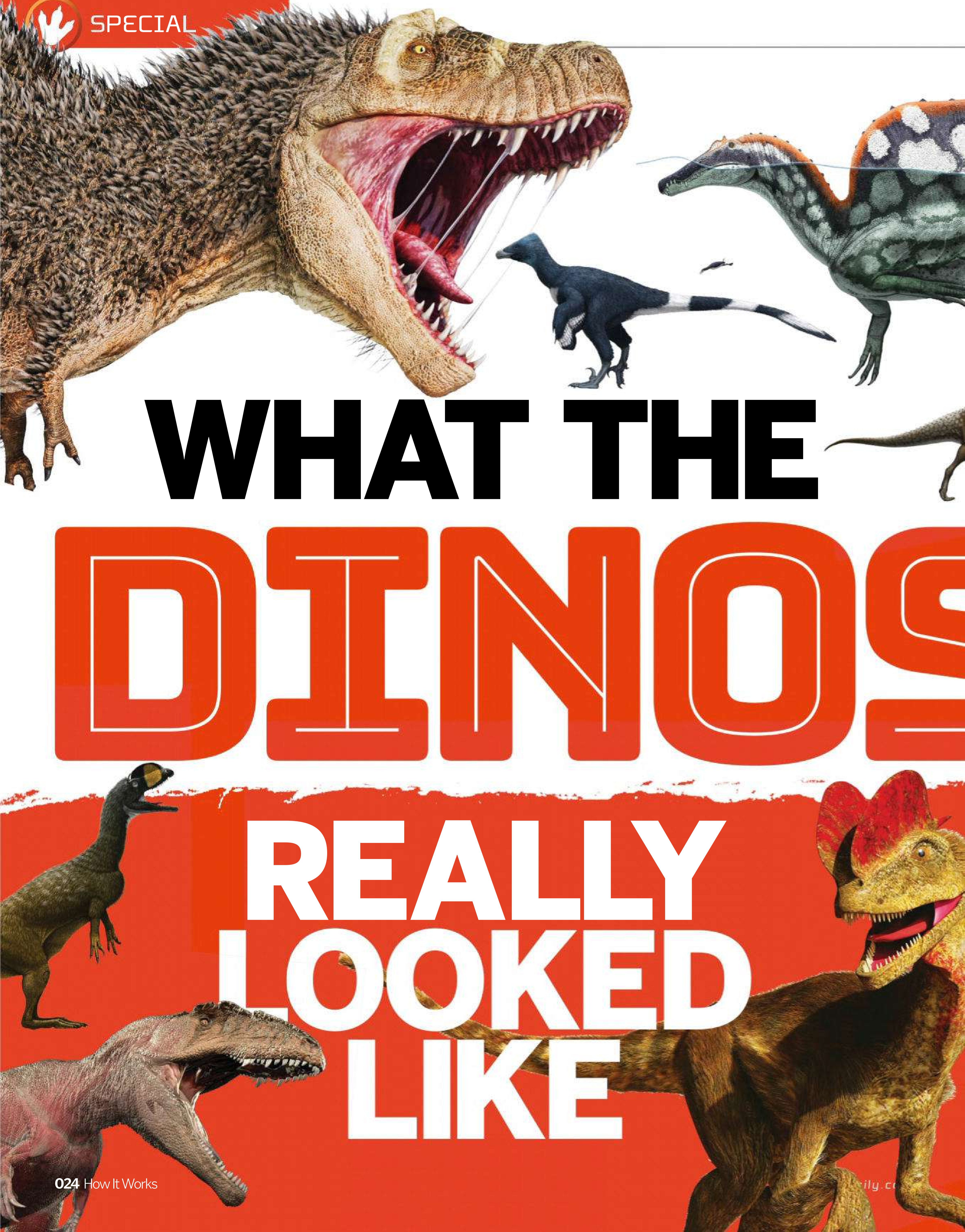
JouleBug

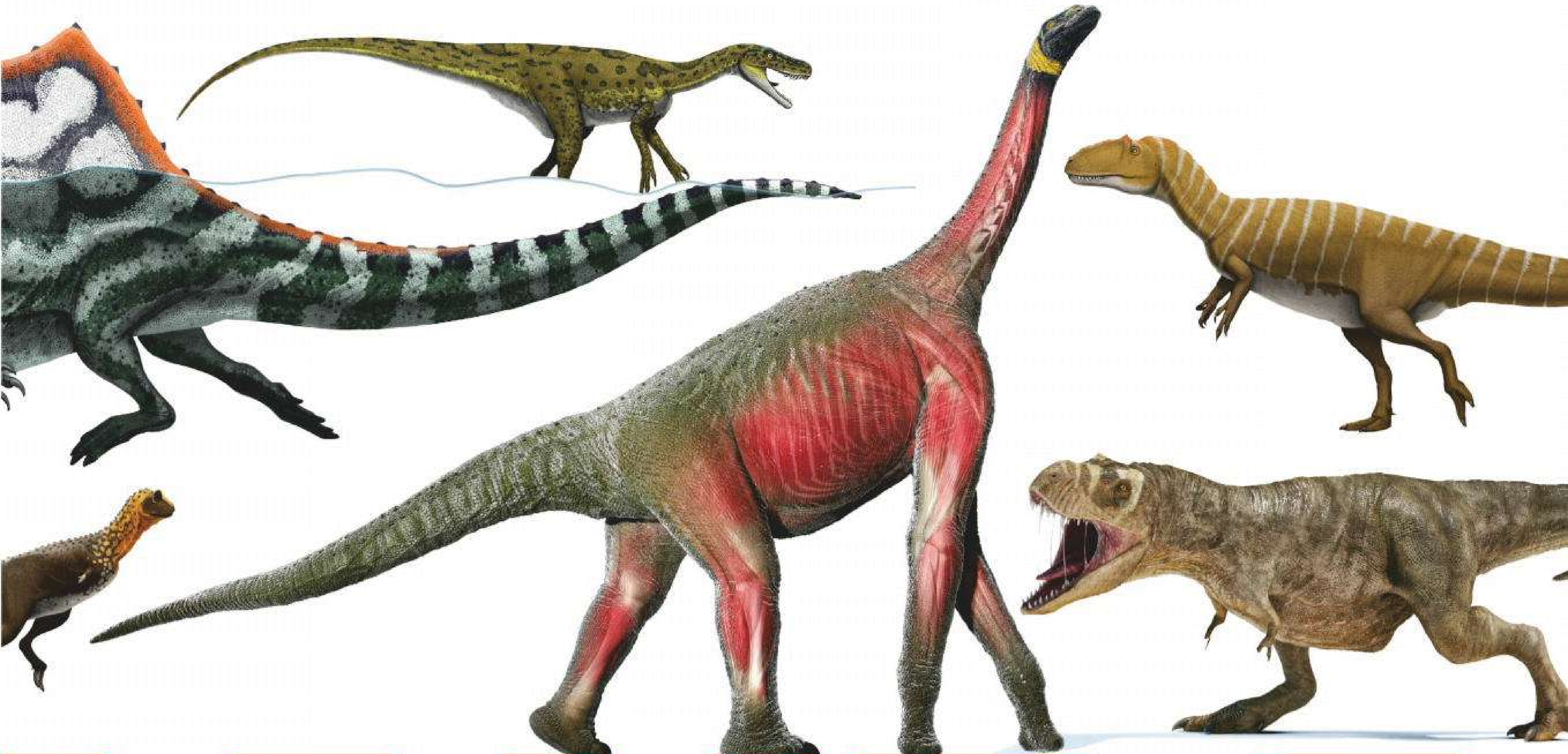
■ Developer: **Joulebug / Cleanbit Systems, Inc.**
■ Price: **Free / Google Play / App Store**

Access a whole host of sustainability tips and actions to take into your everyday life to be more sustainable, while completing challenges and earning points to share with other users.



WHAT THE DINOS REALLY LOOKED LIKE



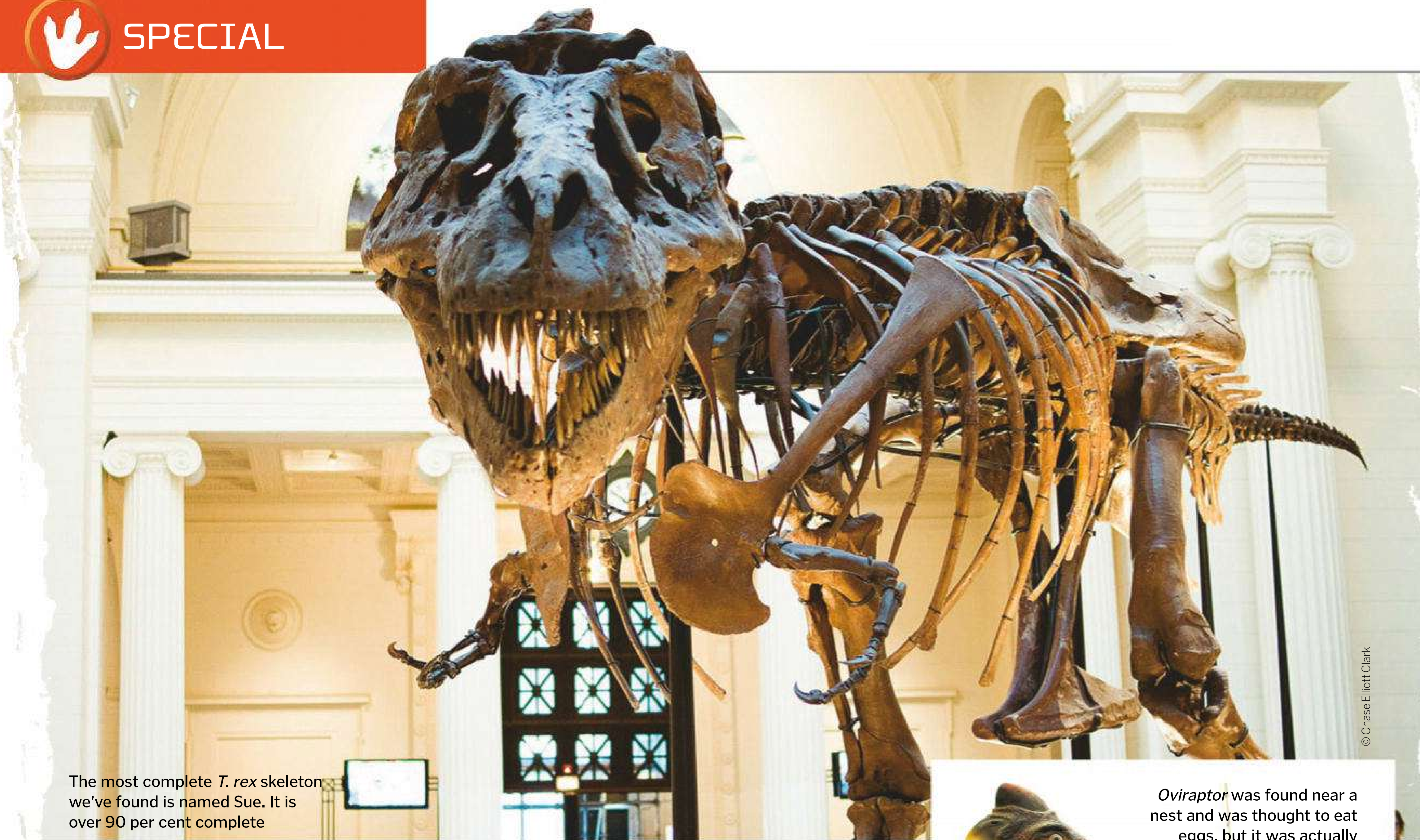


SAURS

HOW INCREDIBLE NEW DISCOVERIES ARE BRINGING THE THESE PREHISTORIC BEASTS BACK TO LIFE

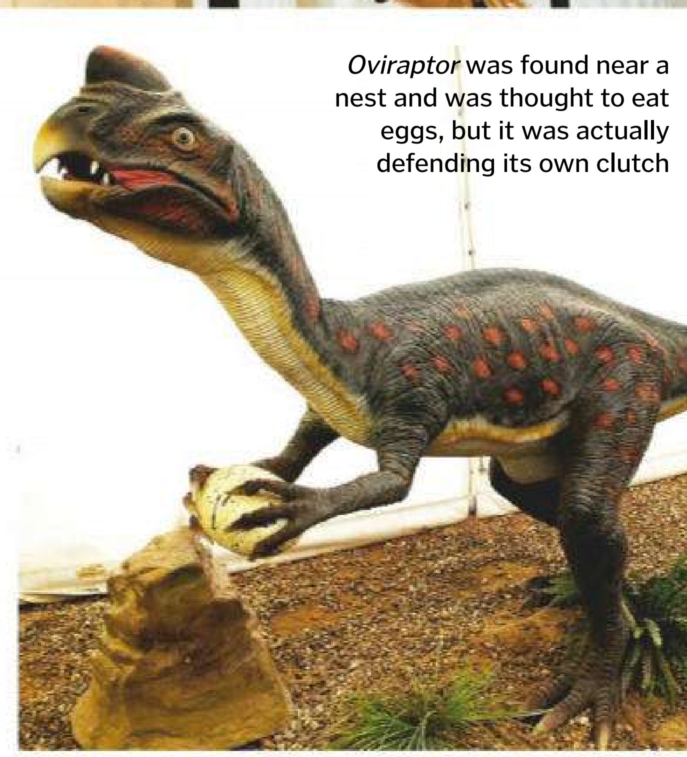
Words by **Amy Grisdale**

The reign of the dinosaurs began just after the biggest mass extinction Earth has ever seen. 70 per cent of land animals and 96 per cent of marine species were obliterated in a mysterious cataclysmic event around 250 million years ago. Evidence shows this Permian-period extinction happened in phases. It could have been a series of giant meteor impacts or an influx in volcanic activity that caused fires and explosions worldwide. It's possible a sudden surge of methane from the ocean floor caused abrupt climate change.



The most complete *T. rex* skeleton we've found is named Sue. It is over 90 per cent complete

© Chase Elliott Clark



Oviraptor was found near a nest and was thought to eat eggs, but it was actually defending its own clutch

© HombreDHojalata

Whatever happened, it appears to have been quick. The surviving animals entered a new geological era, during which they would go on to dominate the planet. Vegetation exploded in the absence of so many animals, and after a period of 10 million years conditions were just right for new species to thrive. A group of reptiles called archosaurs took control and began to adapt to their new surroundings in the middle of the Triassic period. Dinosaurs of every shape and size roamed the Earth for the next 170 million years, from crow-sized Microraptors to the blue-whale-sized Argentinosaurus. The last dinosaurs died out in the most recent mass extinction that paved the way for humans to evolve. Their fossilised remains lay buried for millions of years before humans even existed.

Dinosaur remains weren't recognised for what they truly were until 1824. Oxford University professor William Buckland studied bones that had been discovered some 150 years earlier by naturalist Robert Plot. While Plot was convinced they were remnants of a race of giant humans, Buckland knew they must have been from some kind of carnivorous lizard. He called his new discovery *Megalosaurus* – 'Great lizard'.

"Dinosaurs of every shape and size roamed the Earth for the next 170 million years"

In the 19th century new discoveries were met with some scepticism. Amateur fossil collector Mary Anning found the first complete plesiosaur skeleton in 1824. Experts had their doubts. Georges Cuvier was famous for founding the study of vertebrate biology and gave his name to over 50 animal species that are still alive today. He voiced his concern that the find was a hoax. He was certain there were too many bones in the neck for the animal to hold it up and suspected the fossil was two species fused together.

The Geological Society agreed that something dubious was going on and called a meeting to

Prehistoric forensics

© Raul Martin

Dinosaurs were fast healers and survived injuries that would have been deadly to the average mammal

We can determine the cause of a dinosaur's death by examining bones, footprints, skin, teeth and eggs. Physical trauma could be fatal, such as damage from another animal. Fights must have been brutal. A fossil of the theropod *Allosaurus fragilis* found in Wyoming, US, in 1991 had 19 fractures. Another was uncovered five years later with 13 damaged bones literally from head to toe.

Bone diseases could cause death through deformities, tumours and infections. We can even recognise healed fractures and identify what species left tooth marks in fossils. Remains with a rough texture indicated the animal suffered a degenerative disease. A virus that originated among the dinosaurs may be responsible for hepatitis B today.

There are conditions that dinosaurs had when they died but were not necessarily the cause of their demise. Several specimens had infected or missing toes, and trace fossils show animals limping. Dinosaurs even got ticks and fleas.

Finding footprints

Dinosaurs left impressions in mud that could harden into stone. We measure their dimensions, but there is more information hidden in a trace fossil. We can glean skin texture, the length of their strides and even deduce complex behaviour like building nests. Footprints left by *Eubrontes* 200 million years ago, found in modern-day North America, were startlingly similar to modern birds. They show a sequence of a dinosaur stopping for a rest by the lake. There are footprints leading to a divot created when it squatted down, then steps leading away while the tail dragged on the ground.


Tracks left by carnivorous dinosaurs in the early Jurassic period near Tuba City, Arizona


Measuring the vertebrae of the giant sauropod *Futalognkosaurus*, the most complete of its kind discovered to date

The story of bones

Bones give us huge clues about a dinosaur's size, posture and locomotion. Scientists can reconstruct muscle and cartilage by examining marks on bone. Erosion to the teeth tells us what the animal ate. CT scans build up 3D images of bones by taking panoramic X-rays. We've found that a great deal of dinosaur bones contained air sacs like birds do. Using this technique we can figure out how old a dinosaur was, what its skin looked like and even the size of its brain. Muscles and skin can be layered onto reconstructed skeletons in order to create accurate pictures of long-dead dinosaurs.

Signs in skulls

A dinosaur skull is a goldmine. It contained the eyes, mouth, nose, ears and the brain of the animal. We have learned an incredible amount about dinosaurs by studying their skulls.

Scientists digitally recreated a T. rex skull and rebuilt the muscle by researching the jaws of birds and crocodiles. They found it had a bite force of about 5,800 kilograms, the hardest bite of any terrestrial animal in history. The muscles responsible for closing the jaws grew exponentially when the animal matured and were extremely large, even for such a big animal. This figure is not agreed upon by all dinosaur researchers.

We know that *Spinosaurus* was adapted for swimming because of the position of its nostrils. They were far back on the top of the narrow skull, a lot like a crocodile's. It was probably bigger than *T. rex* judging by the length of the snout, possibly reaching 16 metres long.

Q&A

The big dino questions

We spoke to Eofauna's dinosaur experts about how they create accurate models of these extinct creatures

What can fossils tell us about a dinosaur and its appearance?
It depends heavily on the quality of fossil data. The more complete the remains are, the more accurate the dinosaur representation will be. If a skeleton is fairly complete, we can restore the shape of the animal accurately. This requires adequate knowledge of comparative anatomy for reproducing good digital reconstructions of muscles and bones. We usually use modern birds, but distantly related animals like elephants are useful for sauropods in terms of biomechanics and posture.

Did most dinosaurs have scales or feathers?
All dinosaurs had scales but some, especially the most advanced theropods, also possessed feathers. Only a few... species had developed secondary feathers. Dinosaurs probably all had simple developing feathers we call filaments.

Can we be sure what colour a dinosaur was?
No. Apart from a very few cases where melanosomes have been preserved, we can only speculate. Colours can be estimated from the animals' lifestyle, size and the climate they inhabited.

Asier Larramendi and Rubén Molina

Scientific directors at Eofauna

Asier and Rubén are the founders of Eofauna, a company that creates scientifically accurate representations of prehistoric fauna. Asier's work focuses on the comparative anatomy, body size, biomechanics and functional morphology (shape) of extinct vertebrates. Rubén specialises in biogeography, biometrics, ichnology (footprints) and bibliographic documentation.

What big questions do we still have about dinosaurs?
One of the trickiest issues is how to determine a dinosaur's sex. It has been the focus of many studies but has been found to be more complex than we first thought. Other mysteries include what their behaviour and cognitive abilities would have been like. Living animals are good in these aspects, but there is very little evidence in dinosaurs.

settle the matter. After a long debate, Anning's plesiosaur was confirmed to be legitimate. However, it wasn't a bad idea to take discoveries with a pinch of salt because forgers had already begun to scam museums with fake fossils.

The dawn of palaeontology was an exciting time, but many researchers thought it was too early to be drawing conclusions from such a small record. Others documented all the information they could, but it involved a lot of paperwork. Everything had to be written down, from fossil databases and family trees to painstaking statistical analysis. German palaeontologist Heinrich Georg Bronn was at the forefront of logging dinosaur data. He used innovative methods to represent information that were new at the time, like graphs. He built up a database by studying what fossils looked like and crunching the numbers. The index he published in 1849 demonstrated when certain species appeared and disappeared at different times and was a remarkable breakthrough.

Radioactivity was discovered in 1896, and it wasn't long until it could be used to measure geological time by studying the rate of decay of naturally occurring radioactive isotopes. This helped determine the age of fossil rocks, and by the end of the century scientists had worked out a rough timeline of when these creatures lived. They began to realise the planet was much older

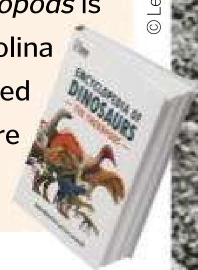
> "Forgers had already begun to scam museums with fake fossils"

than they had previously thought and started to see geological history very differently.

The invention of computers had a big impact on data analysis, as a lot of information could suddenly be processed by a machine in a short time. Computers transformed the entire discipline of palaeontology. Huge databases have been built online, and computers are able to model the relationship between fossils and life on Earth now. Perhaps most importantly, we can build up images of what dinosaurs looked like using precise imaging techniques. There's a lot we still don't know, but we're making new discoveries all the time.

Learn more

The Encyclopedia Of Dinosaurs: The Theropods is written by Eofauna researchers Rubén Molina and Asier Larramendi, beautifully illustrated by Andrey Atuchin and Sante Mazzei. More information at www.eofauna.com.

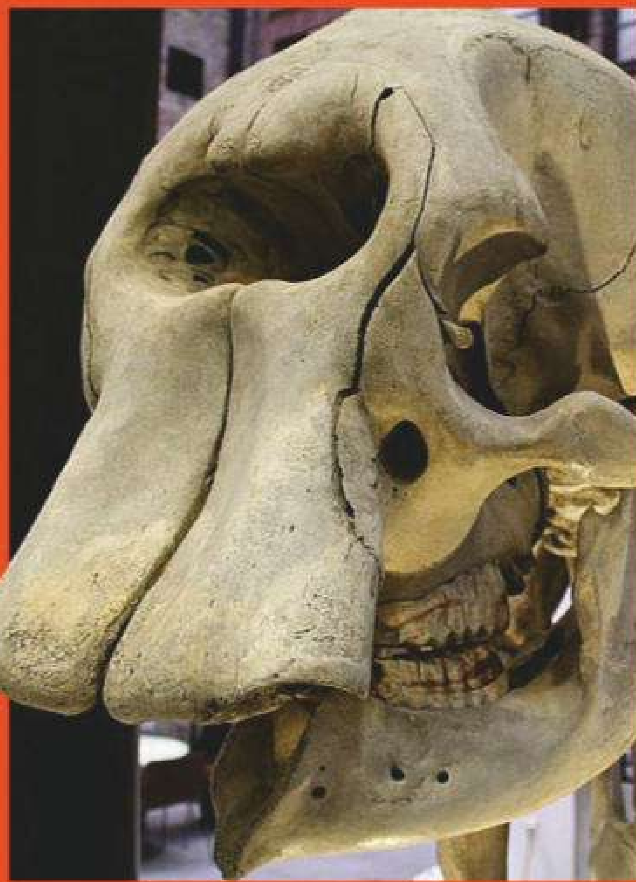


Dinosaur myths and legends

Remains of large, extinct animals have been found throughout history, long before we knew what they were. The enormous bones inspired people to speculate about what bizarre creatures might exist in the vast world around them.

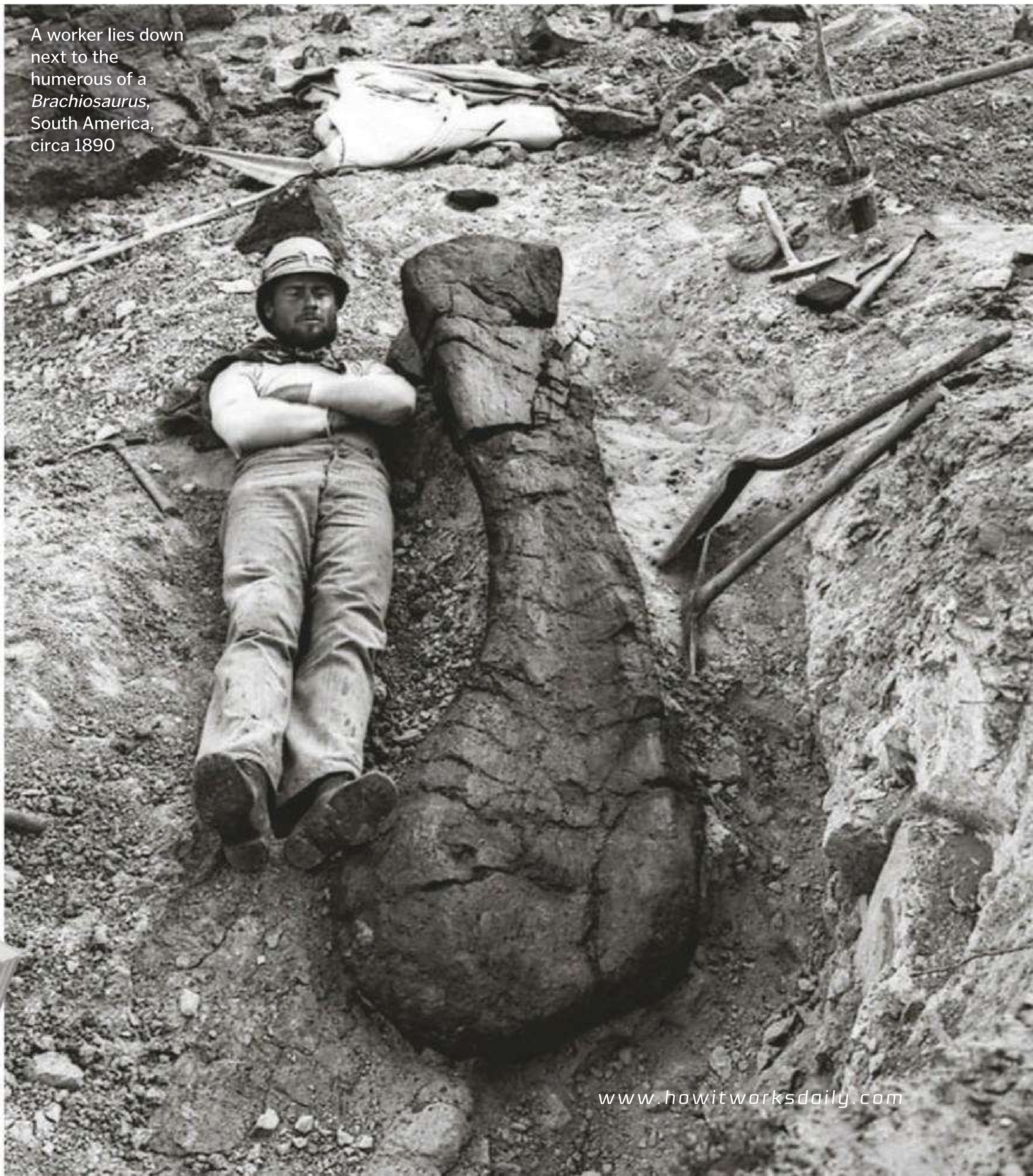
Circular holes in skulls of extinct elephants might have convinced ancient Greeks of the existence of the one-eyed cyclops. It's been suggested that griffins, sphinxes and sea monsters had their origins in fossil remains too.

There's a good chance dinosaur remains also sparked myths about dragons. It would explain why they are part of mythology in so many cultures across the globe, and have been for a very long time. Sculptures of dragons in China date back to around 6000 BCE. They were constructed by Neolithic humans and were probably worshipped. Chinese historian Chang Qu wrote about dragon bones in around 300 BCE, but we don't know what animal they really came from.



© John Cummings

The eye-shaped opening in an elephant skull is actually where the trunk attaches to the face



A worker lies down next to the humerous of a *Brachiosaurus*, South America, circa 1890

© Leon Becker

200 years of dinosaur development

Our understanding of *Iguanodon* has changed dramatically over the centuries we have been studying it

1822
The first *Iguanodon* teeth are found by Mary Ann Mantell and studied by her husband Dr Gideon Mantell. Georges Cuvier states his belief that they may have been from an extinct hippo-like animal.

1825
The fossilised teeth resemble those of an iguana, only many times larger. Mantell names the creature *Iguanodon*, which means 'iguana tooth'.

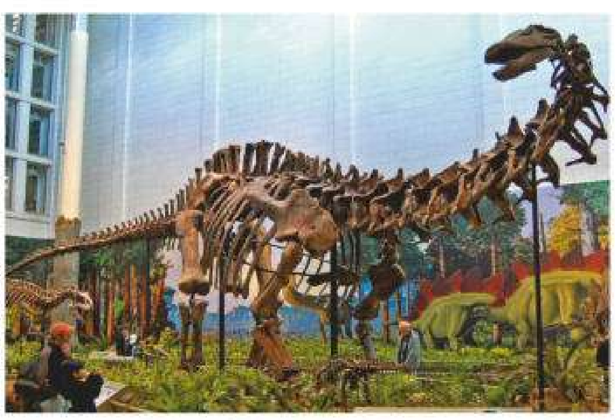
1853
Sir Richard Owen and his associate Benjamin Hawkins reconstruct *Iguanodon*. They put its spiked thumb on the tip of its nose, believing it to be a horn, with the dinosaur standing on all fours.

1872
The spike is recognised as one of a pair of sharpened digits that protrude from the wrists. They are believed to have been used as weapons that served no other purpose.

1882
Dr Louis Dollo rebuilds an *Iguanodon* skeleton, modelling it on the modern emu. The new reproduction stands erect on two legs.

1980
Dr David Norman analyses the dinosaur's tail and realises it wasn't flexible, and therefore *Iguanodon* must have walked on all fours. He also notices its fingers were able to grasp objects.

2005
After studying their footprints we now think Iguanodon was an optional tetrapod able to balance on its back legs. Trace fossils indicate it was around ten metres long.



An *Apatosaurus* skeleton that was misidentified in 1877 and was corrected in 1903

DINO FACTS

15
Kosmoceratops had 12 more horns than Triceratops

A T. rex had 60 serrated teeth that could be up to 20cm long

700
The number of therapod species we have identified so far

75 cm
Therizinosaurus had the longest claws of any animal ever known

Some think *Apatosaurus* could break the sound barrier by whipping its tail

THE OLDEST FOSSIL POO IS MORE THAN 200 MILLION YEARS OLD

HERBIVOROUS DINOSAURS ATE ROCKS TO HELP GRIND UP SWALLOWED FOOD

1cm
The length of the smallest, non-avian dinosaur egg (*Jinfengopteryx*)

WE DON'T KNOW WHY *STEGOSAURUS* HAD PLATES ALONG ITS BACK?

1 METRE
The length of a *Brachiosaurus* foot

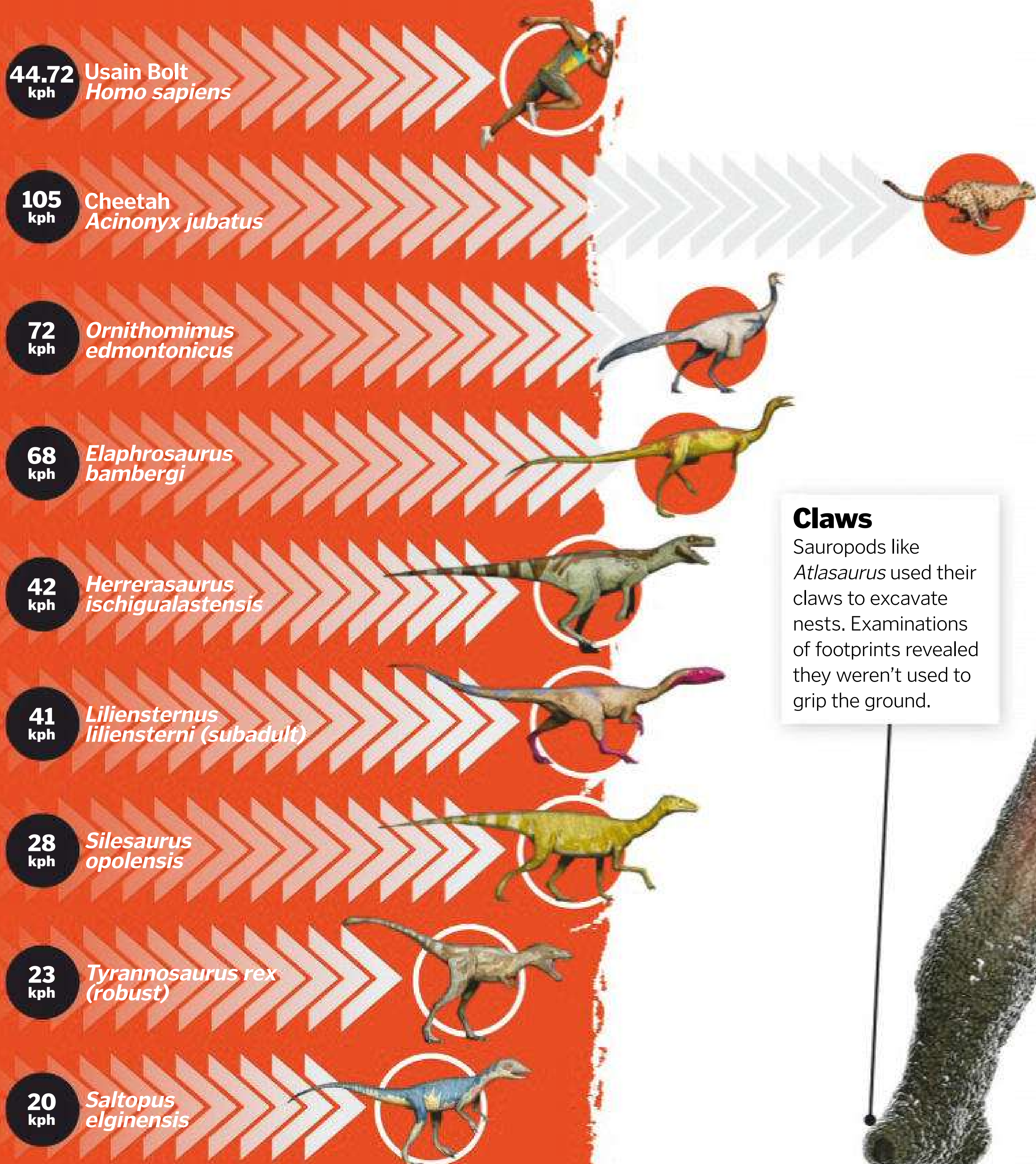
30 YEARS
The typical lifespan of a dinosaur

Champion sprinters

Extinct theropods were seriously quick and a match for fast runners that live today

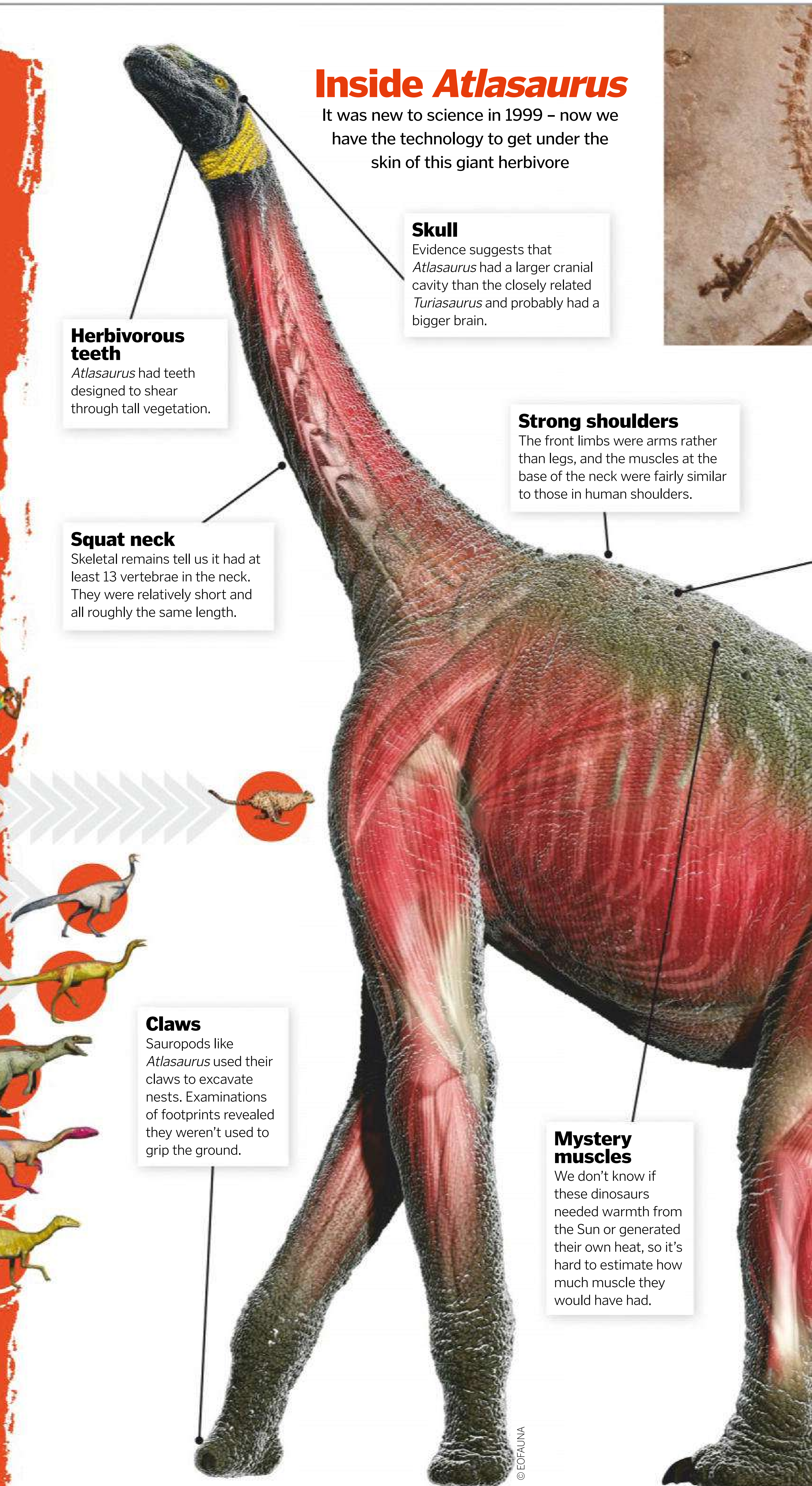
We estimate a dinosaur's speed by considering a number of factors. We look at the length of its strides, how many steps it took per second and the proportions of its leg bones. All of this data is compared to that of modern running birds like ostriches, yielding results that seem logical. The animal's mass also had a significant effect on how fast it could run. *T. rex* was only as fast as the extant roadrunner because it was so heavy.

An animal well-adapted for running is described as cursorial. Estimated values of cursoriality come from body mass, cadence and stride ratio. These numbers are multiplied by the length of the dinosaur's legs to calculate the speed it was capable of reaching.



Inside *Atlasaurus*

It was new to science in 1999 – now we have the technology to get under the skin of this giant herbivore



© Getty

The *Sinosauropteryx prima* was the first dinosaur to be found with feathers

Why were the dinosaurs so big?

The niches left by the victims of the Permian extinction 250 million years ago were soon occupied by the new-fangled dinosaur species. Dinosaurs could eat fibrous plant matter without chewing it. They could consume a lot in a short time and eventually grew to be enormous. Big dinosaurs also had few predators, so size was selected for by nature.

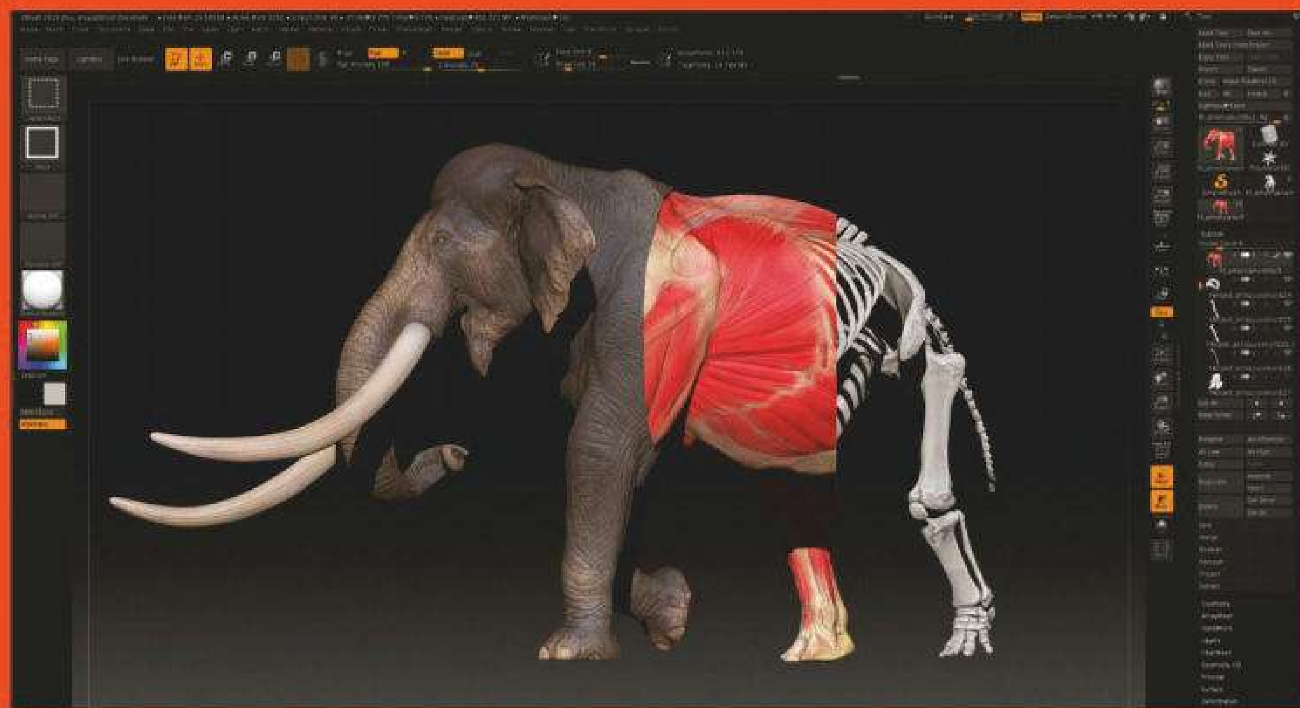
Reptiles could grow much larger than mammals because of their thicker limb bones and huge cartlidges. These shock absorbers reduced stress on the joints, which allowed them to achieve body masses many times that of most large mammals.

Long tail

This dinosaur could have been able to whip its tail in self-defence, but we're still not sure about that.

Long legs

Atlasaurus was essentially on stilts, with limbs seemingly too long for its body. This could have been evolution's way around having to grow a long neck. Rubén Molina is seen in the photo (right) measuring a massive sauropod femur.



© EOFAUNA

Bringing extinct animals to life

Eofauna's Asier Larramendi tells us how scientifically accurate prehistoric beasts are reconstructed in 3D

"We first either visit museum collections to take photos and measurements, or take information about the best-preserved specimens already published in scientific papers. Once we have the proper documentation, we produce a detailed skeletal reconstruction diagram first to have a precise idea of the proportions of the living animal. It is very important to have a well-rounded understanding of how skeletal elements interconnect, a good knowledge on the muscular system of similar living animals today and how other soft tissues (skin, hair, scales, feathers, etc.) are placed in living organisms. This is what is called comparative anatomy.

From this we create a 3D skeleton. In order to make sure its morphology (size and shape) is accurate, we use a photogrammetry technique: we take a series of photographs of the bones from different angles, then digitally generate a 3D model by comparing characteristics in the images. Once the 3D skeleton model is finished by our sculptor Shu-yu Hsu, we add musculature by comparing the extinct species with modern relatives.

For example, if we are working with an extinct proboscidean (elephants and their relatives), the muscle system of modern elephants can be applied [as per *Palaeoloxodon antiquus*, above]. If we are working on a dinosaur, we use living archosaurs (crocodiles and birds).

After this the skin and coverings are added. Sometimes we have very good information on extinct animals' skin and covering, such as hair, scales, filaments or feathers. A great example is the woolly mammoth - some superb frozen specimens have been found. Despite dinosaurs going extinct 66 million years ago, some exceptional specimens have also been found [with soft tissue]. These are useful to create a better representation of the living dinosaurs. Finally, we give dynamic poses (running, walking, etc.) based on skeletal motion ranges and biomechanics."

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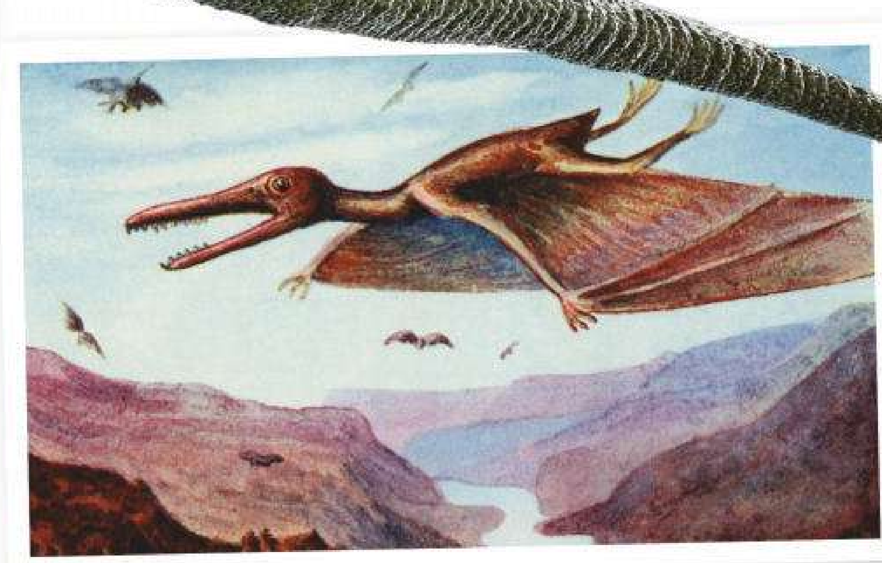

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Even though pterosaurs could fly, birds evolved from two-legged carnivorous dinosaurs

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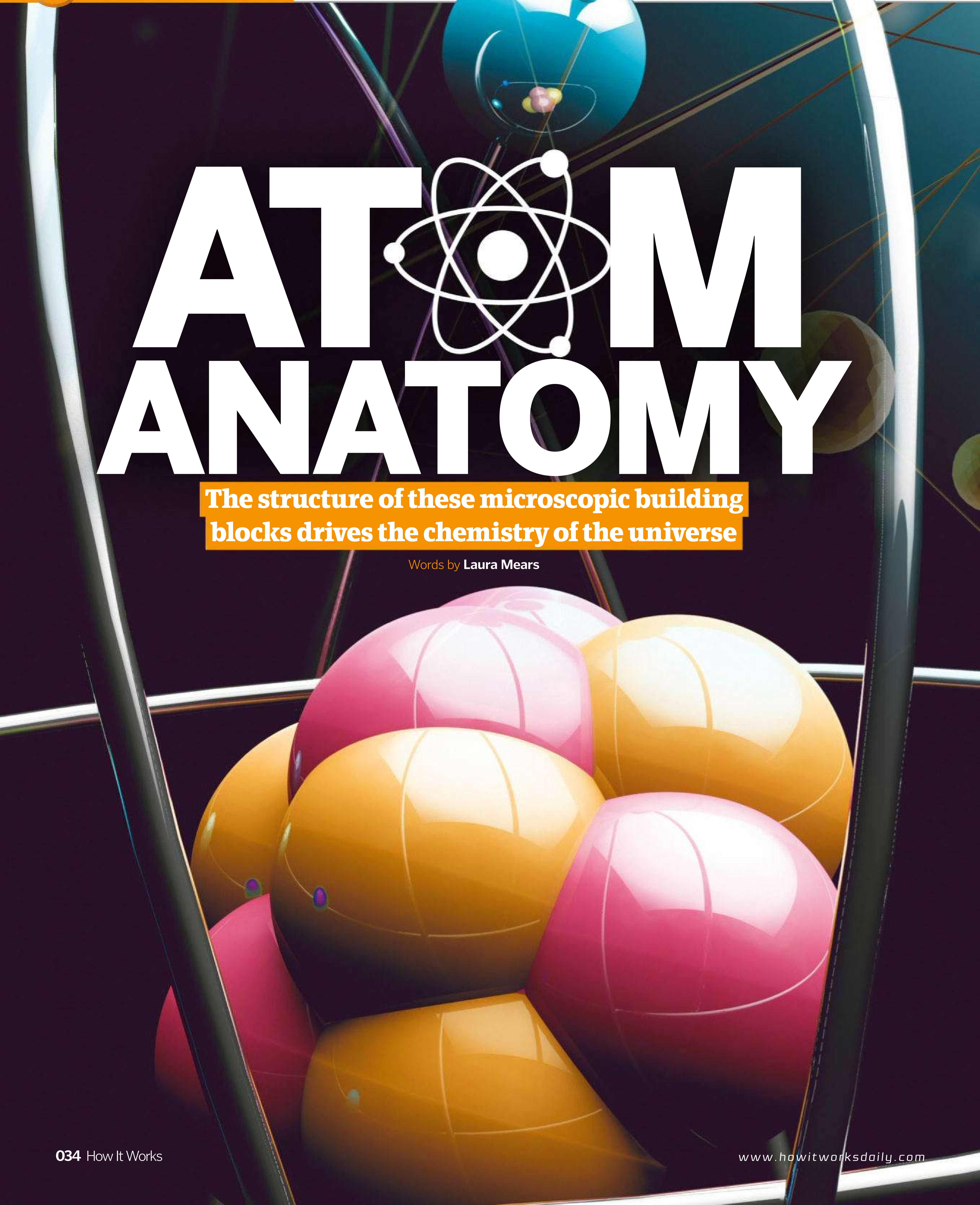
BRAND

So popular that it is one of the Natural History Museum's all-time bestsellers

SIZE

A portable wonder. Small at 11.5 x 8 x 3cm but powerful



ATOM ANATOMY

The structure of these microscopic building blocks drives the chemistry of the universe

Words by **Laura Mears**

DID YOU KNOW? *Oxygen is the most abundant element in Earth's crust, followed by silicon, aluminium and iron*

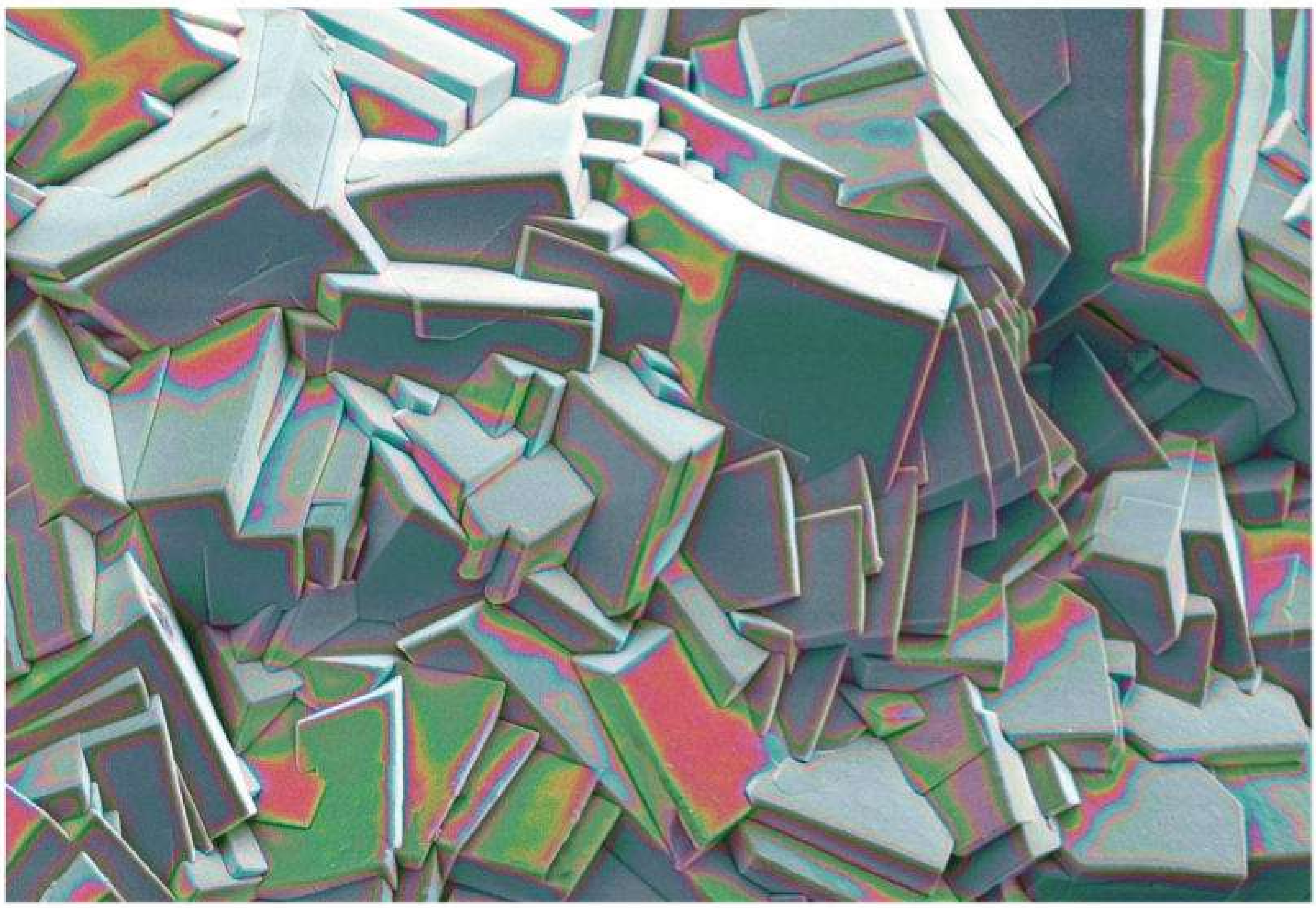
Atoms are the building blocks of everything around you, from the cells in your body to the cup of tea in your hand. Made from elementary particles and held together by fundamental forces, they drive the chemistry of the universe.

Each one has a tiny, positively charged nucleus, balanced by a cloud of negatively charged electrons. These determine the atom's properties. Split an atomic nucleus open and you'll find subatomic particles called protons and neutrons. The simplest atom, hydrogen, has just one proton and no neutrons. But as you move up through the periodic table the number of protons rises one by one. With each extra proton, the behaviour of the atom changes.

Protons have a positive charge, so for every extra one added the atom also gains another negative electron. These electrons cluster in fixed zones around the atomic nucleus, known as orbitals or shells. Each shell can only hold a certain number of electrons. So when a shell fills up, the next electrons have to start a new one.

Atoms are most stable when their electron shells are full, but most elements have electrons to spare. This is the driving force behind the chemistry we see around us. To complete half-filled shells, atoms form chemical bonds. They can either share their electrons to form

> "Split an atomic nucleus open and you'll find subatomic particles"



These are sugar crystals magnified 1,250 times by a scanning electron microscope

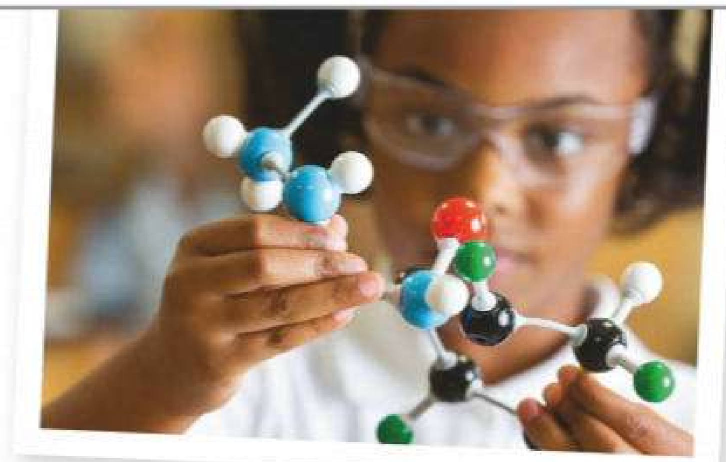
The birth of atoms

13.8 billion years ago the Big Bang created the universe. In the first moments it was so hot and dense that no particles could survive. Whenever quarks and electrons burst into existence, they immediately broke apart. But as the universe expanded and started to cool, these elementary particles became more stable. Then quarks started to come together to form protons and neutrons. Within minutes, these were combining to form the first atomic nuclei.

It took another 380,000 years for the universe to cool enough to allow complete hydrogen atoms to form, and then the real magic started to happen. Gravity started to pull the atoms into clumps, and as those clumps grew the pressure inside started to build. The atomic nuclei got so close together that they started to fuse, and the first stars burst into life. These vast nuclear furnaces have been fusing atomic nuclei ever since, creating all the different elements we see around us today.

© NASA

Hydrogen atoms were the first to form after the birth of the universe



Different elements can combine together to make complicated compounds

What your tea's made of

There are more atoms in a cup of tea than cups of water in all the oceans

MIXTURE

Your cup of tea is a mixture; a combination of different molecules and compounds not linked by chemical bonds. It contains water, as well as the molecules from the tea itself: polyphenols, amino acids, enzymes, pigments, volatiles and caffeine. Perhaps milk is there too, which contains fats, proteins and sugars. And maybe also table sugar.

Scale: **10 centimetres**

COMPOUND

If you stuck a powerful microscope into your tea, you'd start to see the compounds that make up the mixture. Compounds are substances made from two or more different elements bonded together. Caffeine has the chemical formula $C_8H_{10}N_4O_2$. It contains eight carbon atoms, ten hydrogens, four nitrogens and two oxygens.

Scale: **0.78 nanometres**

MOLECULE

Break caffeine into pieces and you'd end up with molecules. These contain just one type of atom and are the smallest units that can take part in chemical reactions. If you broke the caffeine compound up, its oxygen atoms would pair together, forming an oxygen molecule with two identical atoms.

Scale: **292 picometres**

ELEMENT

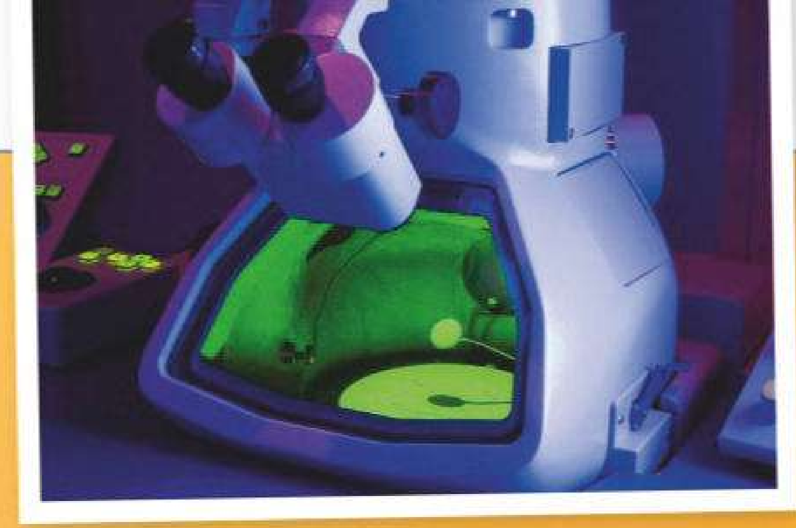
Zoom in on an oxygen molecule and you'd see the individual oxygen element. Elements are substances that contain only one type of atom. There are over 90 naturally occurring elements on Earth, and even more made synthetically in laboratories. Oxygen is element number 8.

Scale: **60 picometres**

ATOM

One final zoom would reveal the subatomic particles inside the atoms: positive protons, neutral neutrons and negative electrons. The numbers of each give different elements their distinctive chemical properties. An oxygen atom contains eight protons, eight neutrons and eight electrons.

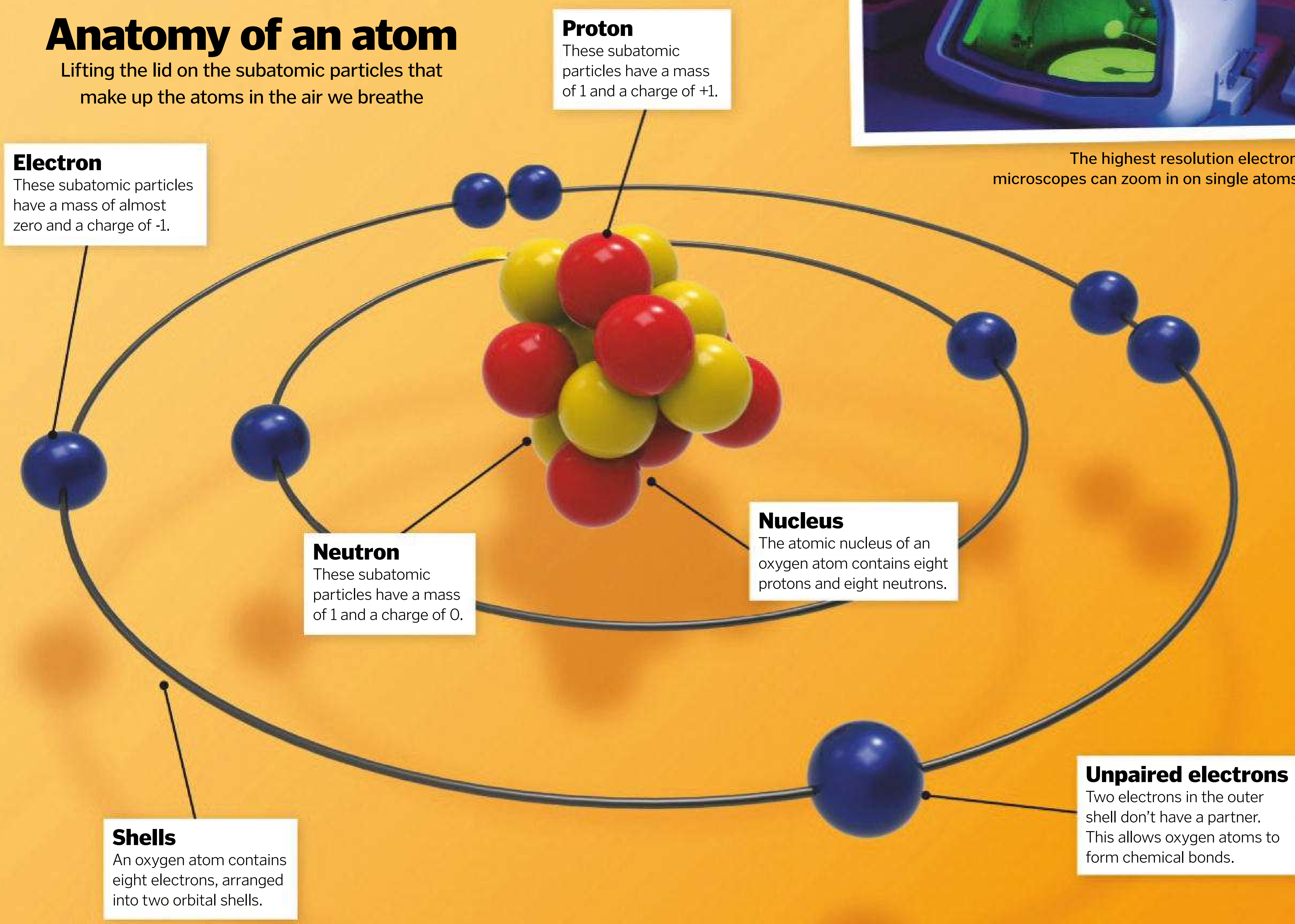
Scale: **1 femtometre**



The highest resolution electron microscopes can zoom in on single atoms

Anatomy of an atom

Lifting the lid on the subatomic particles that make up the atoms in the air we breathe

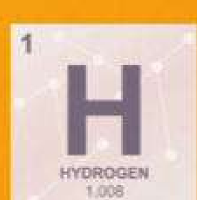


ATOM FACTS

118
Number of elements in the periodic table

90
Number of elements that exist in nature in appreciable quantities on Earth

75%
Most of the matter in the universe is hydrogen



2.6 secs

A new chemical is being made with speedy regularity

50 million
CHEMICALS HAVE BEEN DISCOVERED OR MADE BY HUMANS

7,700
The number of chemicals currently in use in industry

Stars made all of the elements heavier than hydrogen and helium

covalent bonds, or they can steal electrons from one another to form ionic bonds.

Covalent bonds are common inside our own bodies. Carbon atoms need four electrons to complete their outer shell, so they share with up to four other atoms, including other carbons. This makes them perfect for forming large biological molecules like DNA.

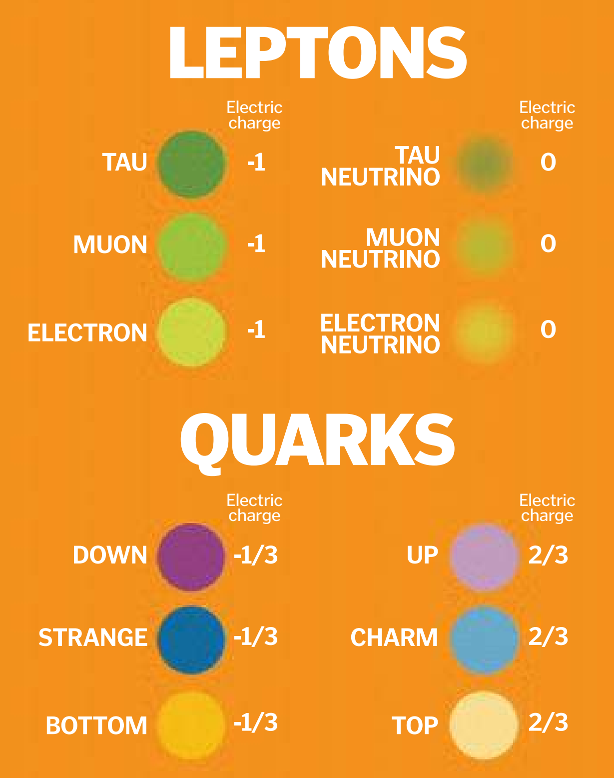
Ionic bonds are more commonly found in the ground. They happen when a non-metal steals electrons from a metal, becoming negatively charged. At the same time, the metal becomes positively charged. These ions attract one another, sticking together in repeating structures, like salt crystals.

> *"They can share their electrons to form covalent bonds, or they can steal electrons"*

Bonds between atoms can break and reform, allowing the elements to perform some amazing chemical tricks. They combine to produce larger compounds, decompose to form smaller ones, or swap one element for another to produce a chemical with different properties. These dynamic interactions are happening all around us, all the time.

Smaller still

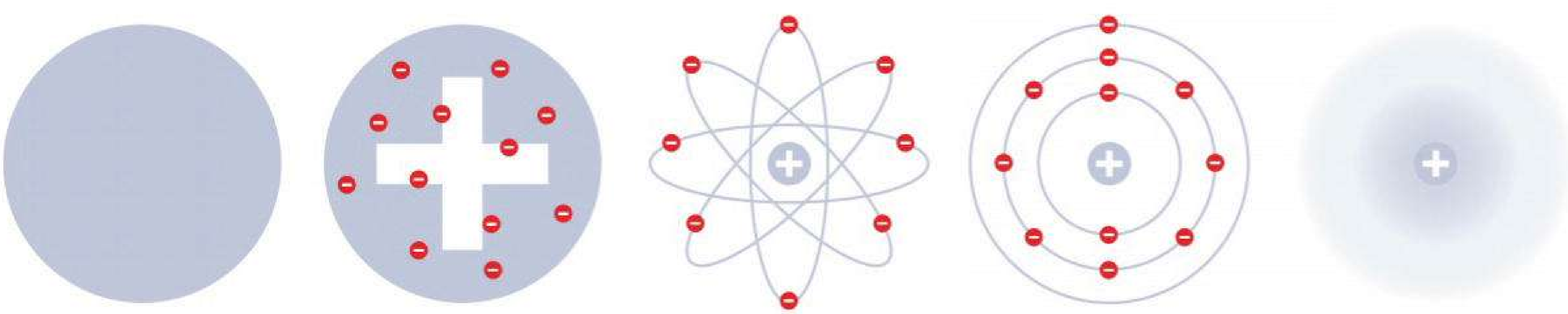
The protons and neutrons that make up the atomic nucleus aren't the smallest components of matter. These are the 'elementary particles' – quarks and leptons. There are six types of quark, arranged into pairs: up and down, charm and strange, top and bottom. They have a partial electrical charge and a 'colour charge' of red, green or blue. There are also six types of lepton: electron, muon, tau and their associated neutrinos. It takes seven particles to make up the simplest hydrogen atom: two up quarks and one down quark for the proton; one up quark and two down quarks for the neutron, and one electron to orbit around the outside.



There are six quarks and six leptons, each with different properties

Atomic evolution

Our understanding of atomic structure has come a long way in the past 200 years



1803 Solid sphere

John Dalton was the first to describe atoms. The word came from the ancient Greek 'a', meaning 'not', and 'temnein', meaning 'to cut'. He thought that they were indivisible.

ACCURACY

Dalton recognised that different types of atom had different properties. But he didn't realise they contained smaller subatomic particles.

1904 Plum pudding

J.J. Thomson discovered electrons and made a new model of the atom to include them. He stuck them inside a sphere of positive charge, like fruits in a cake.

ACCURACY

This model recognised that atoms contained smaller components, including electrons. But the structure was wrong; the atomic nucleus was missing.

1911 Nuclear

When Ernest Rutherford tried firing tiny particles at atoms, most passed through. This revealed that most of the atom is empty space, with a small nucleus at the centre.

ACCURACY

A positive nucleus surrounded by negative electrons is close to our modern understanding of atoms. But Rutherford hadn't quite captured how electrons move.

1913 Planetary

Niels Bohr's planetary model describes electrons travelling in orbits called 'shells'. They are a fixed distance from the nucleus and have a fixed energy level.

ACCURACY

The planetary model explains why small elements absorb and emit certain frequencies of radiation. However, it runs into problems as elements get heavier.

1926 Quantum

Rather than think of orbitals as circular paths, Erwin Schrödinger imagined them as probability clouds. There is a 90 per cent chance of finding an electron somewhere inside its orbital.

ACCURACY

This model is the most up to date. Thinking of electrons as waves in clouds of probability helps to explain the behaviour of subatomic particles.

The World Health Organization recommends that everyone has ten routine immunisations

How vaccines save lives

These injections, drops and sprays train your immune system to fight deadly diseases

Made up of millions of individual white blood cells, the immune system patrols the body in search of germs. When tissues are under threat, it mounts a two-pronged attack. First, the innate immune system gets to work to slow germ growth and prevent spread. Then the adaptive immune system comes in to eliminate the threat.

The adaptive immune system has powerful weaponry, but it takes a while to deploy. This is because the cells of the adaptive immune system can each only attack one type of infection. When the body encounters a new germ, it needs to find the right cells and prepare them for battle. This process can take up to one week, and in that time people can sometimes become very unwell.

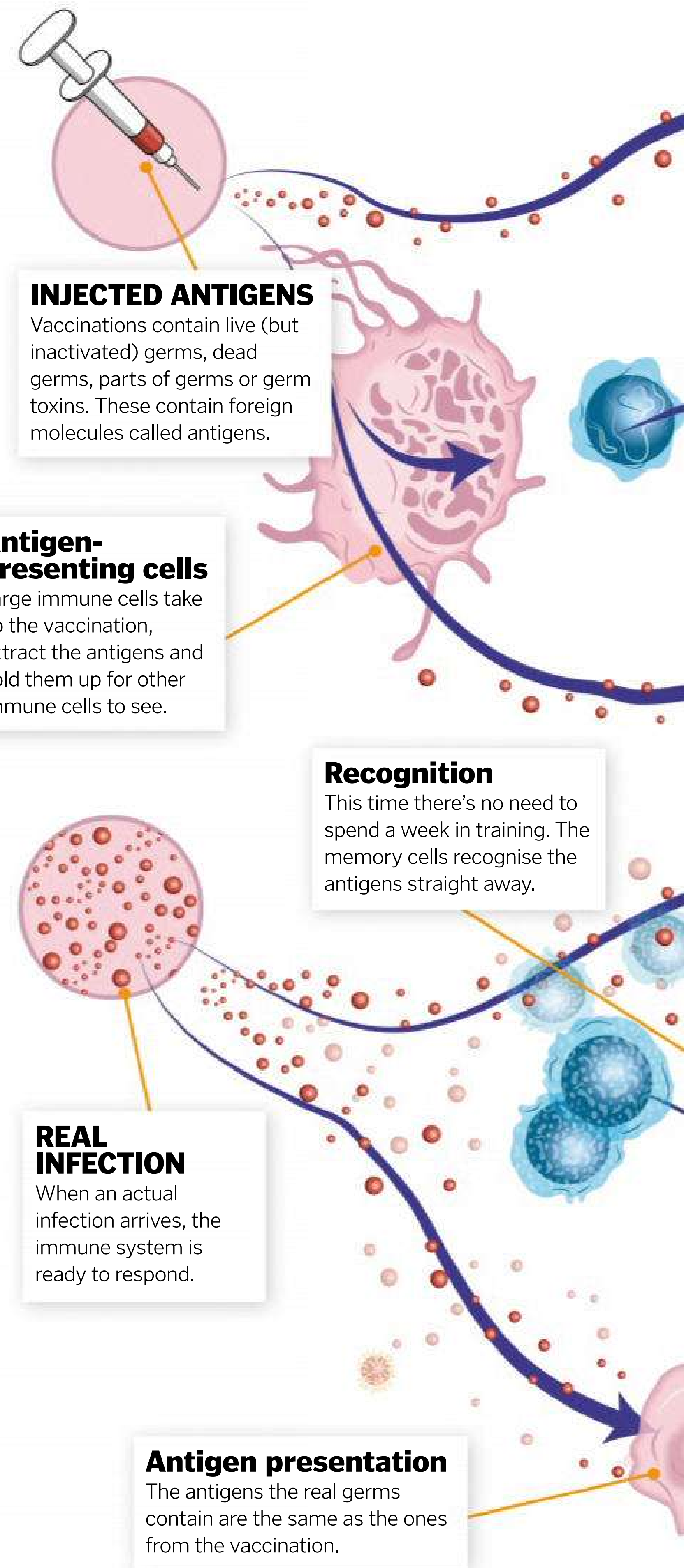
This is where vaccines come in. Rather than wait to encounter a dangerous disease like measles in the world , a vaccine gives the immune system a chance to prepare in advance. Vaccines contain weakened or dead germs, or parts of germs, along with something called an adjuvant. This helps to alert the immune system to danger, encouraging it to start mounting an attack. With access to parts of the germ, the immune system can find the right cells and get them ready.

Many of the cells made during a vaccination disappear afterwards, but some stick around as 'memory cells'. They stay in the bloodstream for decades, constantly on the lookout for their matching germ. If the infection then happens for real, these memory cells spring into action straight away. They divide to produce an army of clones that appears in a matter of hours instead of days. This can clear the infection before it takes hold, preventing us from getting sick at all.

Falling vaccination rates are causing measles outbreaks in the US and Europe

What happens when you're vaccinated?

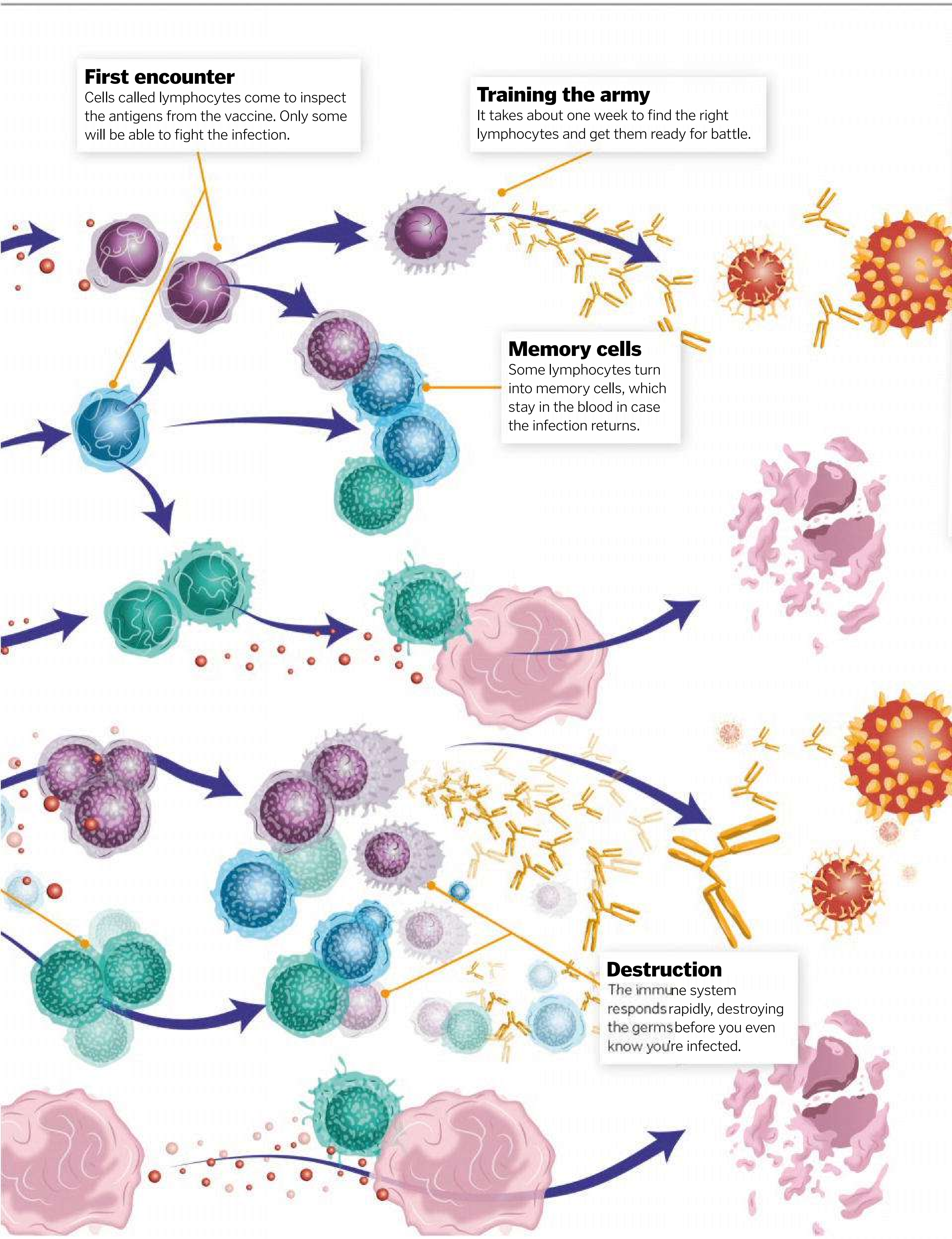
Vaccinations prepare the immune system to fight infections with speed and precision



Are vaccines dangerous?

Without our current vaccinations, 2.5 million children would die every year. If we used the same vaccinations to immunise more children, we could save 1.5 million more lives. But in some countries vaccination rates are dropping. To stop the spread of measles, 95 per cent of children need to have had their MMR vaccine, but in England in 2017–18 uptake was only 91.2 per cent. At this level herd immunity stops working and the virus can start to spread.

There are some concerning vaccine myths, but the truth is that vaccinations save lives. Babies are able to cope with millions of germ cells every day; vaccinations won't overload or weaken their immune systems, even if they were born prematurely. It's safe to vaccinate children if they have a mild illness or allergies. There is absolutely no link to autism. And if you or your children haven't had vaccinations, it's never too late to go and get them done.



Before vaccinations, iron lungs helped children to breathe when polio paralysed their muscles

5 FACTS ABOUT HOW VACCINES SAVE LIVES

1 Smallpox
Smallpox used to kill 5 million people every year. Now it kills none. Thanks to a worldwide vaccination campaign the disease disappeared in 1980 – the only infectious disease to have been eradicated.

2 Diphtheria
The skin and respiratory infection diphtheria would kill 260,000 people every year if it weren't for vaccination. Immunisation prevents at least 86 per cent of infections worldwide.

3 Whooping cough
Without vaccination, there would be nearly 1 million deaths from whooping cough every year. Immunising young babies has reduced that number by two thirds.

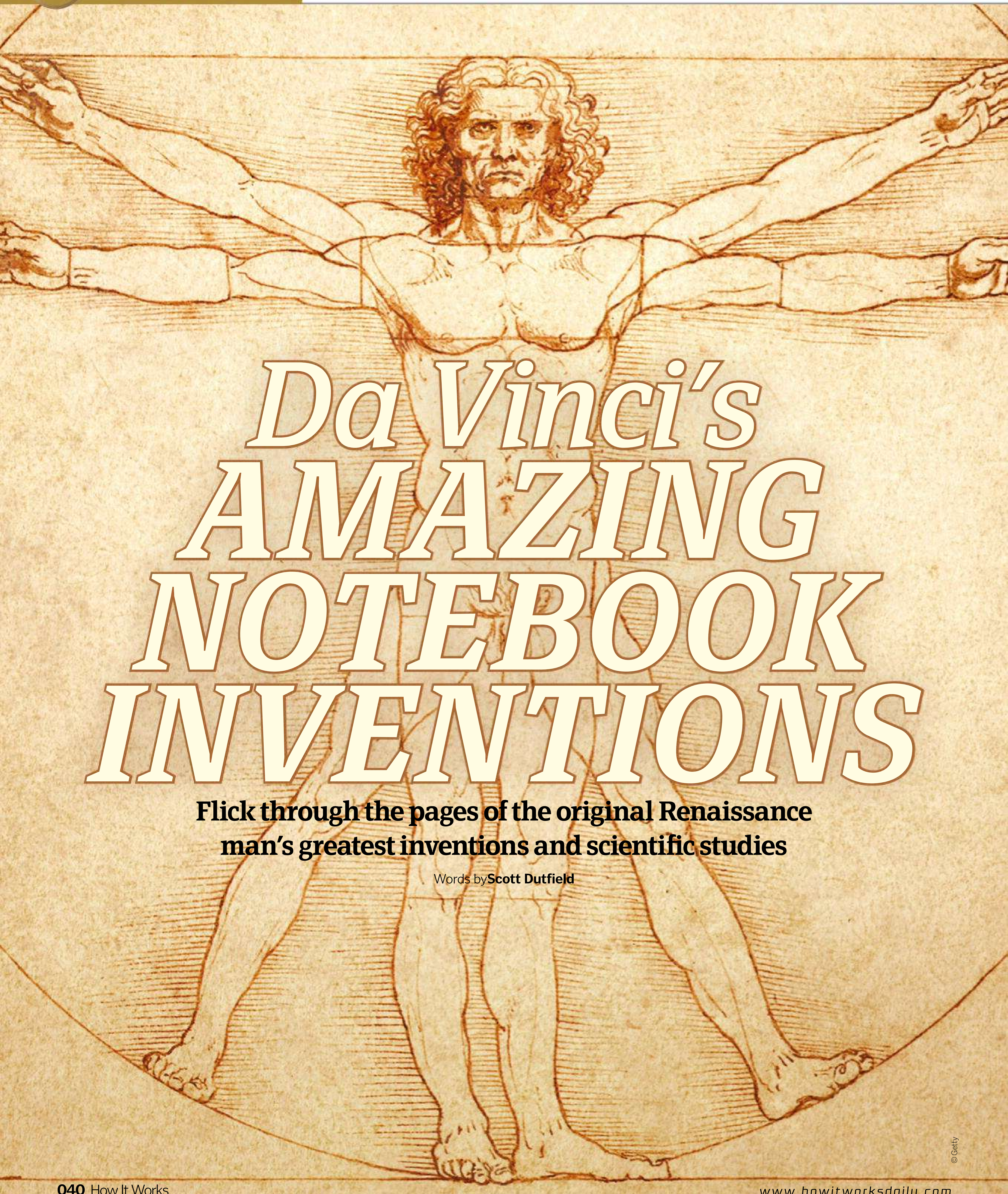
4 Measles
Measles can cause blindness, brain swelling and severe lung problems. It takes just two doses of the vaccine to protect children from infection, preventing 2.6 million deaths every year.

5 Neonatal tetanus
Newborn babies are especially vulnerable to tetanus infection. Thanks to vaccination, 700,000 more babies survive every single year.

Next-gen vaccines

The science of immunisation is only just beginning. The Human Vaccines Project is bringing the world's top scientists together to unlock the secrets of immune response. To design the vaccines of the future we need to understand our own immune defences. The Human Immunome Program is mapping the genes that allow the immune system to make custom antibodies to different germs. The Rules of Immunity Program is discovering what rules the immune system uses to build a defence and remember past infection. The more we know about how our immune system army works, the better we'll get at training it to fight disease.

Flu viruses change every year, so we have to change our vaccines to keep up



Da Vinci's AMAZING NOTEBOOK INVENTIONS

Flick through the pages of the original Renaissance man's greatest inventions and scientific studies

Words by **Scott Dutfield**

© Getty

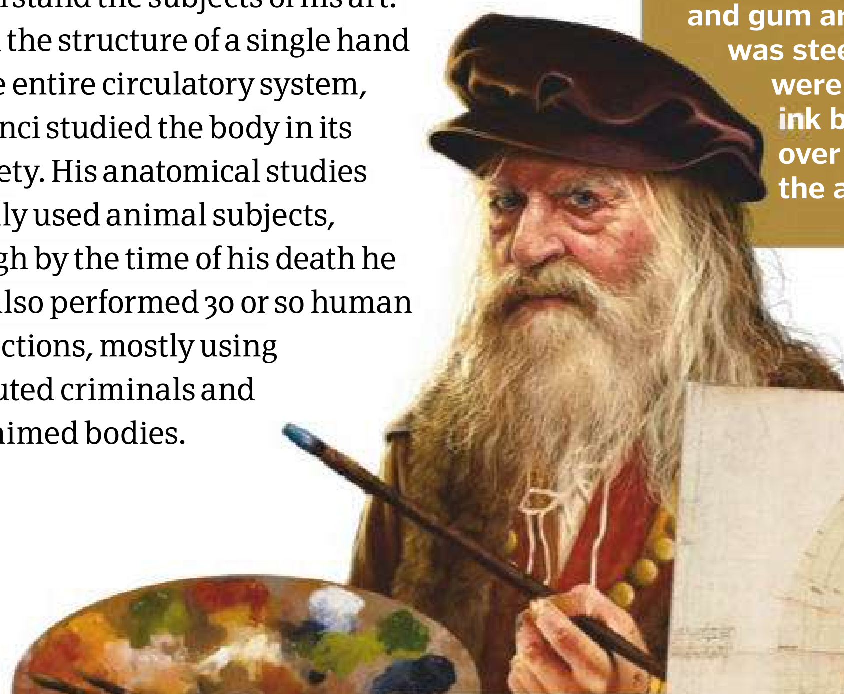
Born in 1452 in Tuscany, Leonardo da Vinci spent his life in the pursuit of knowledge and artistic expression. Now revered for his great works of art, such as the *Mona Lisa* and *Salvator Mundi*, da Vinci's scientific notes suggest his thinking was hundreds of years ahead of his time.

He filled countless notebooks during his career, each bursting with observations about the natural world, the human body and numerous mechanical inventions. One collection in particular, the *Codex Atlanticus*, spans 12 volumes and includes 1,750 drawings.

One of the main focuses in his engineering endeavours, the concept of putting a man in the sky, piqued his interest, and a string of flying machine designs followed. One of his drawings details the design for an 'aerial screw'. Appearing as the ancestor of the modern-day helicopter, this machine was designed to test the air's ability to compress and support human travel in the air. The aerial screw was one of many flying machines conceived by da Vinci, including one that replicated the flapping wings of a bird, but none were made in his time.

Designing multiple other engineering concepts, including weapons, theatrical equipment and hydraulic machines, da Vinci's notes are an inspiration.

Leonardo da Vinci is also well known for the study of the human body – both outside and inside. Around the 1480s his attention turned to the study of human anatomy to better understand the subjects of his art. From the structure of a single hand to the entire circulatory system, da Vinci studied the body in its entirety. His anatomical studies mainly used animal subjects, though by the time of his death he had also performed 30 or so human dissections, mostly using executed criminals and unclaimed bodies.



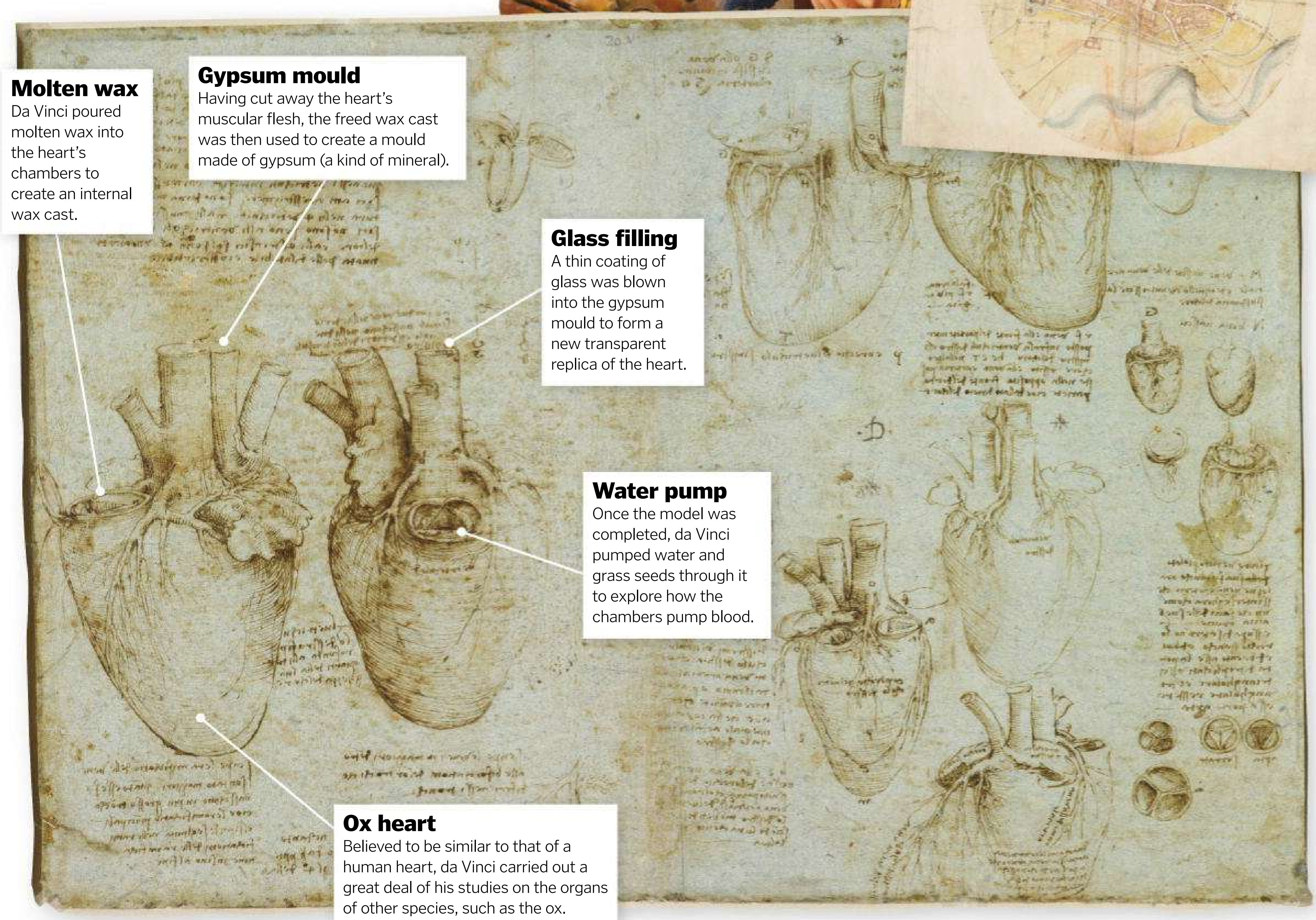
Ink innovation

Made from oak tree galls, iron sulphate and gum arabic, it's a wonder how these three ingredients ever found their way together to produce da Vinci's black ink. At a time when ink was commonly made using home recipes rather than being sold as a product, its manufacture was quite time-consuming. Crushed in a cloth, the oak galls were soaked in rainwater and boiled. The resulting liquid was then strained and combined with iron sulphate and gum arabic. This creative concoction was steeped until all the ingredients were completely dissolved. The final ink began as a pale violet grey, but over several days the exposure to the air turned the ink black.

In his notes, da Vinci mapped the city of Imola, Italy, after being named general architect and engineer to Cesare Borgia, c. 1502

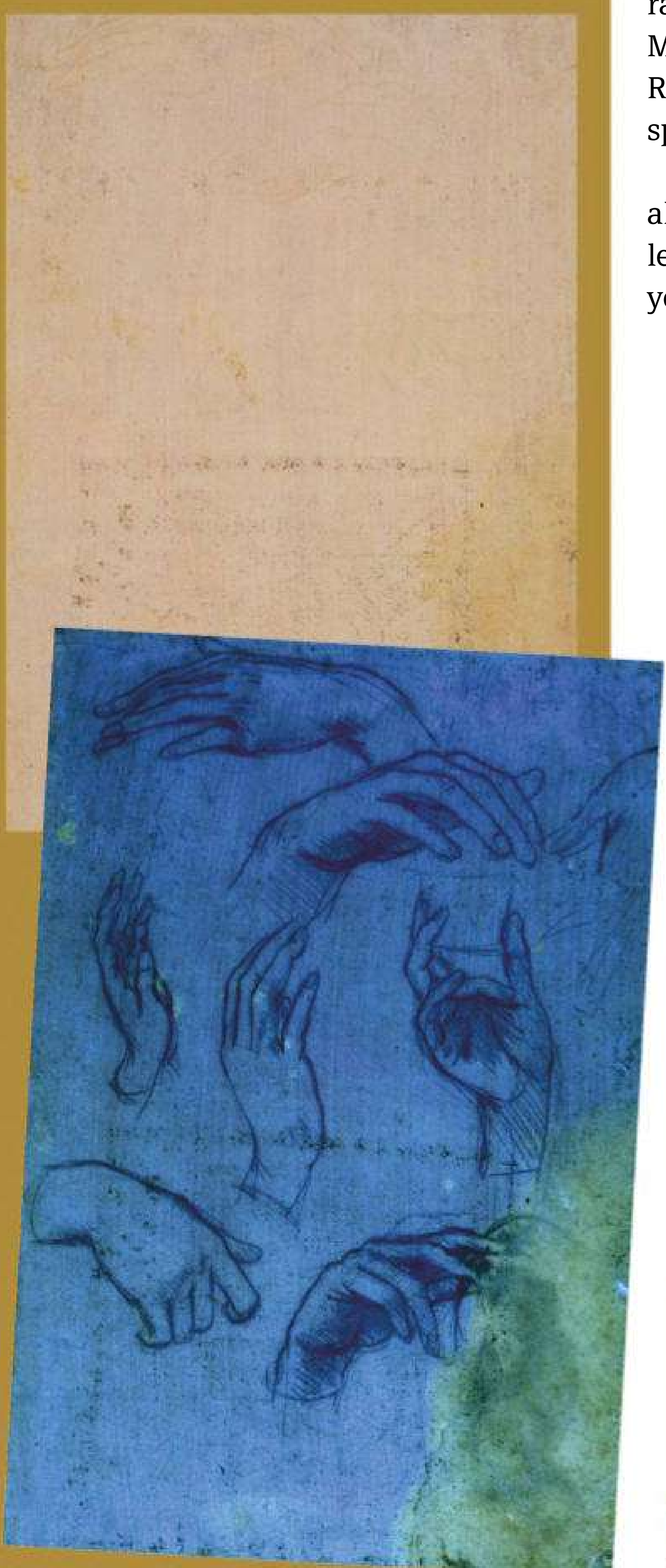
Making a heart of glass

In order to study the inner workings of the human heart da Vinci created a glass model to test his theories



Seeing the invisible

Over time the work of da Vinci, like that of many other artists, is vulnerable to damage from the light, atmospheric or physical erosion. However, with the help of ultraviolet (UV) light previously unseen work is brought back to life. This was the case with a set of hand drawings da Vinci had completed as studies for his painting *Adoration of the Magi*. Invisible to the naked eye, these seemingly blank pieces of paper revealed the illustration when illuminated with UV light. This was due to the type of ink da Vinci usually used. Under UV light certain materials, such as paper, luminesce (glow). The iron-rich ink, though faded, blocks the luminescence, revealing the hidden images on the page.



These drawings of hands, invisible under normal conditions, are illuminated under UV light. They were a study in preparation for *Adoration of the Magi*, created c. 1481

Seen in his surviving notes and anatomical drawings, da Vinci made waves with his near-accurate description of the human heart. Creating a glass heart from that of an ox, da Vinci not only noted its appearance but put his theory of its function to the test. By pumping water through the glass da Vinci deduced that there were vortices (a strong movement of blood) in the heart's chambers. This motion was responsible for the closure of the heart's valves after each pump of blood. It wasn't until the introduction of real-time MRI scanners that da Vinci's work was confirmed as accurate.

"Had he not done anything else in his career, had he not painted a single thing, this would have still marked him out as being one of the great figures of the Renaissance, certainly one of the greatest scientists, both in the depth and the range of his work on human anatomy," said Martin Clayton, head of prints and drawings for Royal Collection Trust at Windsor Castle, and a specialist in the drawings of Leonardo da Vinci.

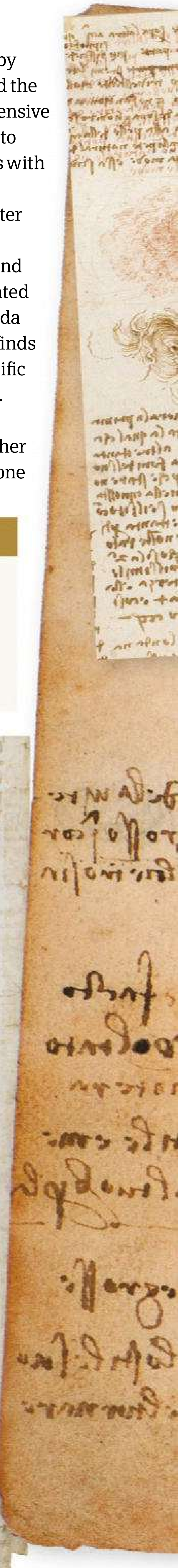
Da Vinci's scientific studies, however, didn't always bear the fruit of scientific discovery and left him still scratching his head. In the later years of his career, da Vinci's notes turned to the movement of water. He thought that by observing water he could understand the basis of force and movement. His extensive notes on the subject of water worked to codify its movement and interactions with the air. He drew the eddies and the circular motions that occur when water pours into a pool, for example.

However, unlike his engineering and anatomical work, this study highlighted some of the fundamental difficulties da Vinci faced. "Leonardo as a scientist finds it very difficult to move from the specific to the general," notes Martin Clayton. "His scientific observations tend to restate endless specific examples rather than overarching principles. That is one of his downfalls as a scientist".

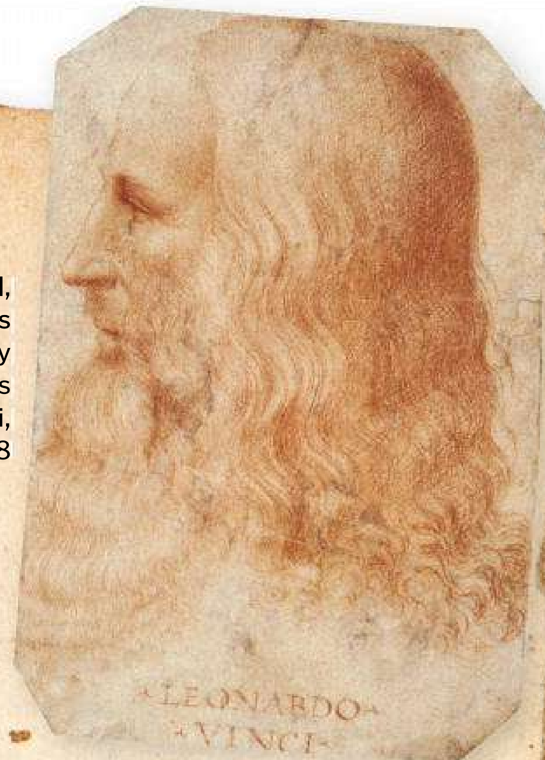
Learn more

Delve deeper into Leonardo da Vinci's notebooks at The Queen's Gallery, Buckingham Palace, where over 200 of the genius's drawings are on display as part of the exhibition *Leonardo da Vinci: A Life in Drawing*, open from 24 May to 13 October 2019.

Da Vinci drew a human embryo within a human uterus with a cow's placenta, believing that mammals shared a common anatomy, c. 1511



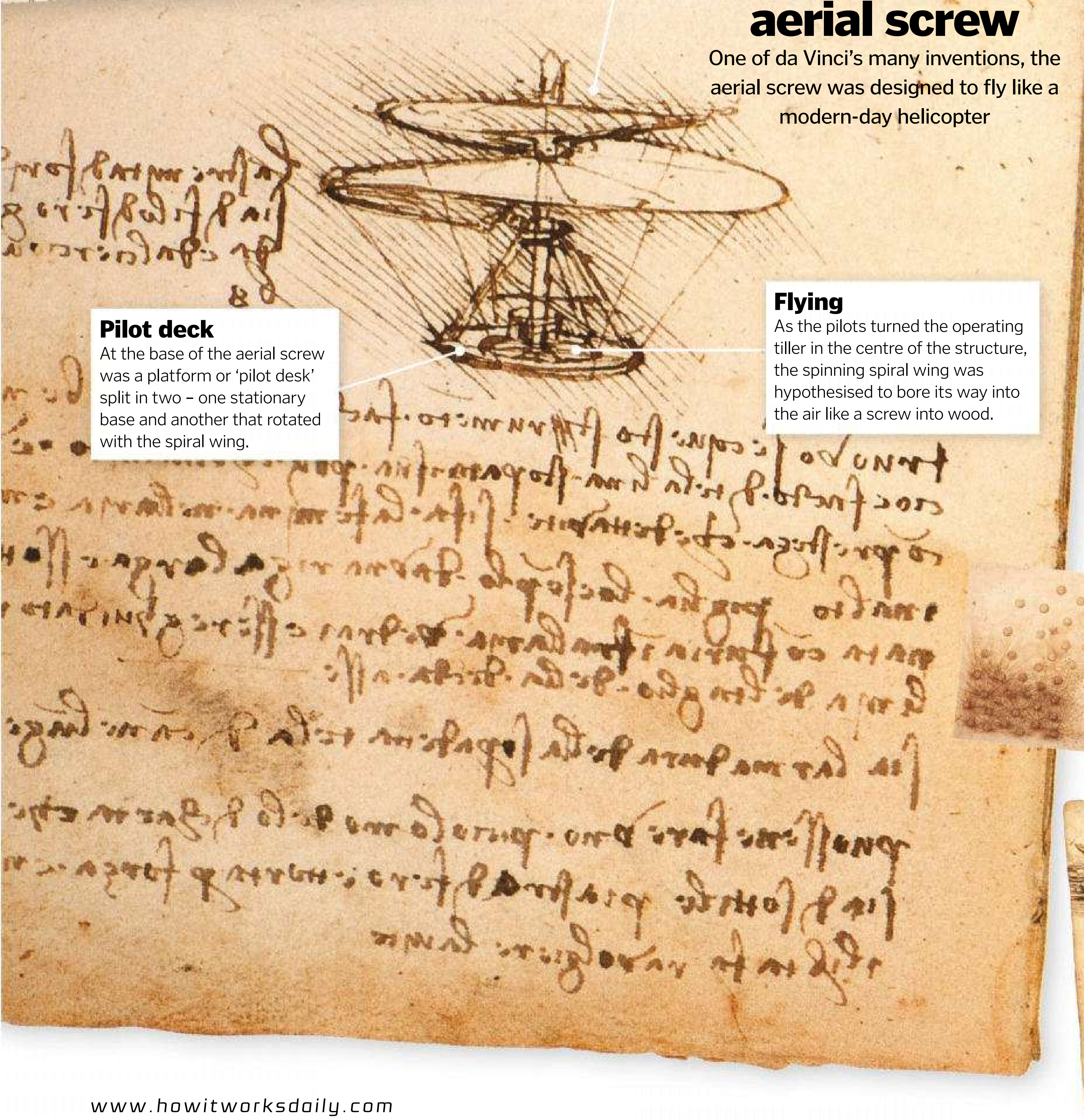
In studies of water, da Vinci noted its movements in relation to physical law, c. 1510–12



Drawn by his pupil, Francesco Melzi, this is one of the only remaining portraits of Leonardo da Vinci, c. 1515–18

Leonardo's aerial screw

One of da Vinci's many inventions, the aerial screw was designed to fly like a modern-day helicopter

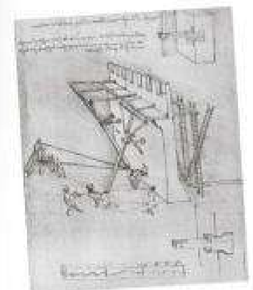


Wing structure
Designed to have an iron frame, wooden ribs and linen covering, this helical structure was supported by a central wooden mast and reinforced with tension lines.

Pilot deck
At the base of the aerial screw was a platform or 'pilot desk' split in two – one stationary base and another that rotated with the spiral wing.

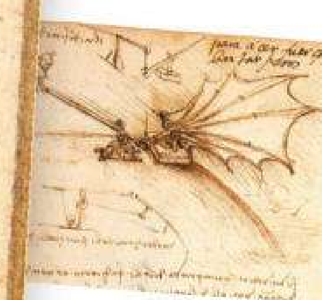
Flying
As the pilots turned the operating tiller in the centre of the structure, the spinning spiral wing was hypothesised to bore its way into the air like a screw into wood.

Da Vinci's inventions through the years

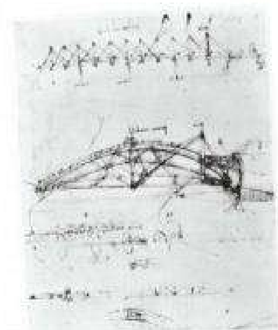


1482–1485
Wall defence
Through a series of levers and beams, da Vinci devises a system to push the ladders of opposing forces away from defensive walls.

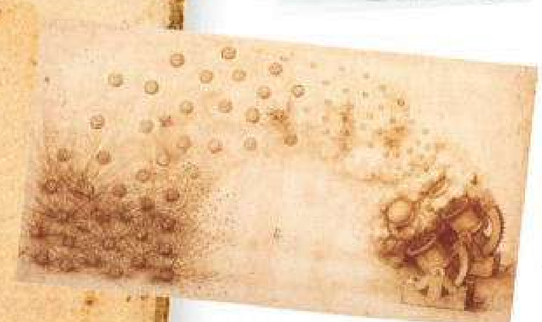
1485
Armoured car
This vehicle is protected by a giant shield, with a series of cannons mounted around the circumference. Fitting a horse inside to drive it would prove impossible.



1487–1489
Flapping wing
To test out his theories of human flight, da Vinci sketches a flapping wing apparatus and a counterweight to see how moving the wing could lift weight.



1487–1489
Swing bridge
Da Vinci notes down three studies of bridges, including a swing bridge and a floating bridge, though the designs never leave the pages of his notebook.



1504
Bombards
Intended for presentation to a patron and not part of his unique studies, these gunpowder-fueled exploding cannonballs are designed to release deadly wedge-shaped iron pieces.

1513–1514
Dredger
During the last few years of his illustrious life, Leonardo da Vinci designs a man-powered dredger that can scoop mud from water systems in order to prevent overflowing.

Rebuilding Notre-Dame


Notre-Dame before, during and after the devastating fire on 15 April 2019

This won't be the first time Paris's famous cathedral has been restored to its former glory

As the inferno engulfed the 850-year-old Gothic Notre-Dame cathedral on 15 April, the world was watching. The despair of Parisians was simulcast to millions of screens across the planet, with the tragedy trending on Twitter. But why is this medieval building a world-renowned landmark?

Notre-Dame (meaning 'Our Lady') is far more than a setting for holiday snaps and postcards. It's an icon of Gothic architecture that houses many amazing artworks and holy relics. While the French kings preferred to be crowned at Reims, Notre-Dame has been witness to many historic events.

Not that time has always been kind to the cathedral. During the French Revolution, rebels destroyed many of its statues, melted down its bells, and after a brief stint using it as a secular 'Temple of Reason', turned it into a warehouse.

Later in the 19th century, when Paris's medieval ruins were being bulldozed, French author Victor Hugo argued they should be preserved. As well as publishing a pamphlet called *War on the Demolishers!*, he wrote *The Hunchback of Notre-Dame* – simply titled *Notre-Dame* in France.

The story of Quasimodo the cathedral bell-ringer captured the French public's imagination. This led to a nearly 20-year restoration of Notre-Dame, starting in 1844. While architect Eugène Viollet-le-Duc went to great pains to repair the damage, he was later criticised for making his own modifications and using more modern materials, such as concrete, to renovate the spire.

Despite further repairs in 1991, the cathedral was in trouble before this year's fire broke out. Ravaged by pollution, the Archdiocese of Paris believed it would cost over £141 million to restore Notre-Dame. While the fire caused even more damage, an international funding effort quickly began to help raise the cathedral from the ashes. Nearly £780 million was donated in the first 48 hours following the fire.

Craftspeople that helped repair York Minster, which was built 15 years after Notre-Dame, could help with the reconstruction

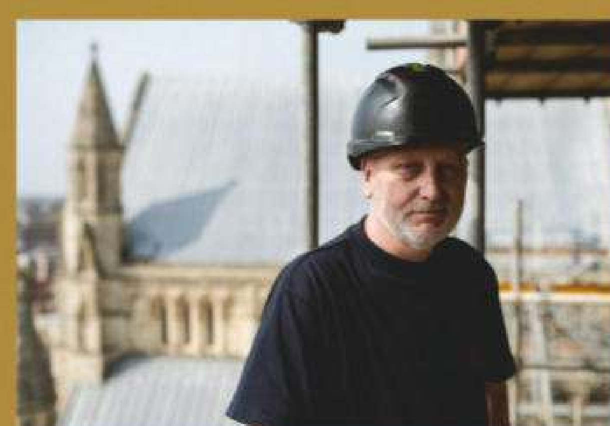

© Alamy

Notre-Dame 2.0

French President Emmanuel Macron has vowed to rebuild Notre-Dame in time for the Paris Olympics in 2024. But could this be possible? After a fire in 1984, it took four years to repair the damage at the similar-sized York Minster in England.

Of course, many of those who worked on York Minster could lend their expertise to Notre-Dame. New technology could also play a role. Laser scans of Notre-Dame from 2015 contain 1 billion data points. These could be used as a high-resolution 3D blueprint to help reconstruct the medieval structure.

A bigger problem may be finding medieval materials. 5,000 oak trees were used to build the original timber roof. In the 19th century, restorers carefully researched the original location of the ancient quarries used for Notre-Dame's masonry. But with the modern geography of Paris transformed, some of these may now prove very hard to find or impossible to access.


© Getty

York Minster's lead joiner Geoff Brayshaw poses above the roof of the South Transept

The cathedral's treasure trove

Crown of Thorns

The most precious object in Notre-Dame's collection is believed to have been worn by Jesus Christ. Given to Louis IX in 1238, the thorns are preserved in a reliquary made of gold and crystal.

© Julie Anne Workman

The rose windows

The cathedral's spectacular stained-glass rose windows are made up of petal-shaped panes, each depicting Bible scenes. The west window is the oldest, from 1125, while the south is a huge 12.9 metres in diameter.

© Eric Chan

The great organ

The largest organ in France, it was rebuilt in the 19th century, but some of its 8,000 pipes date from the 1200s. Organist Louis Vierne played 1,750 concerts before fulfilling his dream of dying at the instrument in 1937.

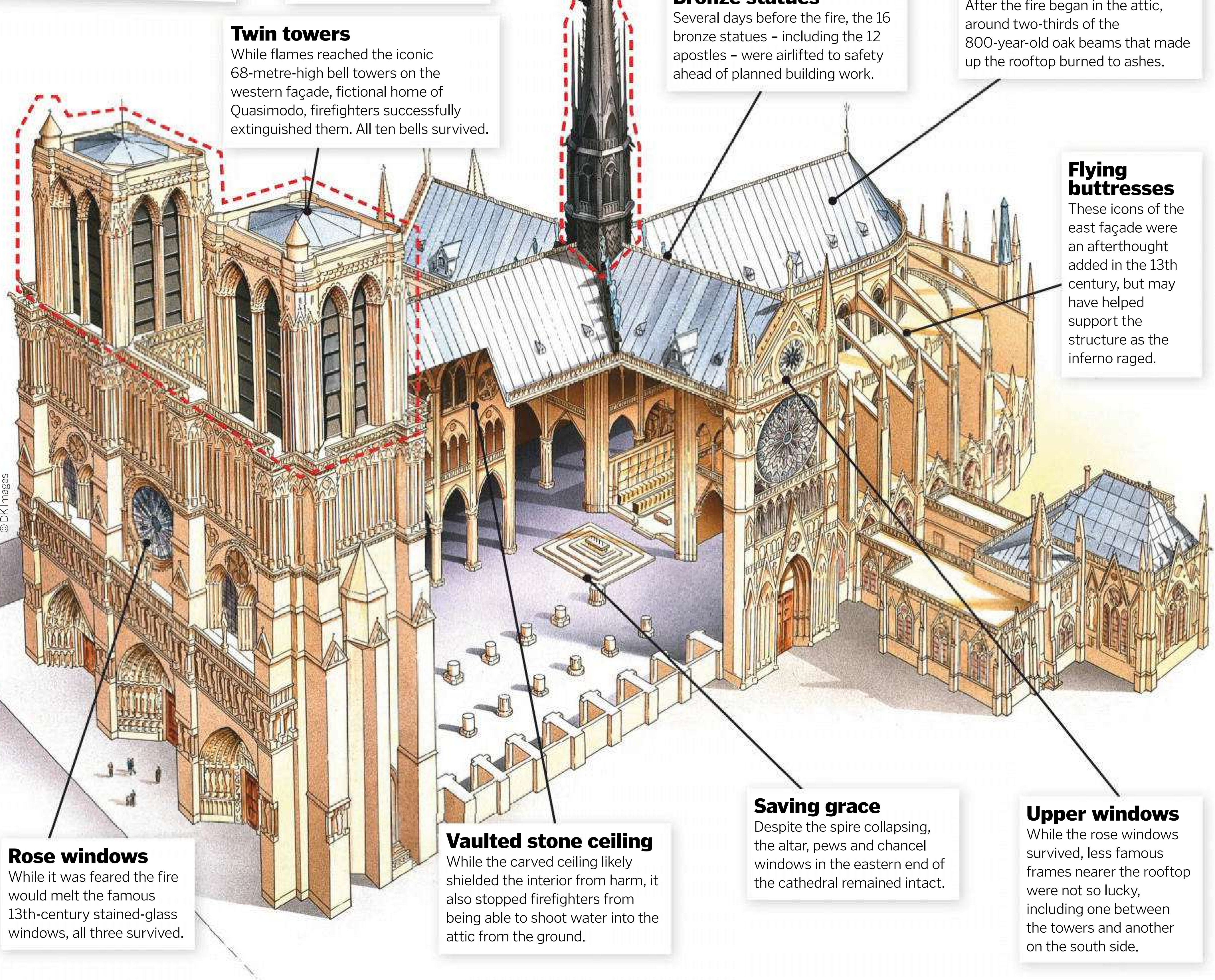
The relics of Saint Denis and Saint Geneviève

Bones, teeth and hair belonging to the patron saints of Paris were destroyed when the spire collapsed. An archbishop had placed them there in 1935 to protect the cathedral.

© Getty

What was damaged?

The blaze came close to bringing down the medieval marvel



© DK Images

How the fire spread
While it was feared the blaze could level the landmark, the flames were mostly confined to the rooftop. Though the exact cause is still being investigated, the fire began in the cathedral attic. This then ripped through the crisscross of 800-year-old wooden beams, which burned to ash. Possibly stoked by sawdust in the attic, the fire also caused the steeple to collapse. Notre-Dame's vaulted stone ceiling shielded the cathedral's interior – including its famous rose windows – from harm. But this masonry also stopped firefighters from being able to shoot water into the attic from the ground.

Gothic spire
Though the original medieval steeple was dismantled in the 1780s, the destruction of the 19th-century reproduction stunned onlookers.

Twin towers
While flames reached the iconic 68-metre-high bell towers on the western façade, fictional home of Quasimodo, firefighters successfully extinguished them. All ten bells survived.

Bronze statues
Several days before the fire, the 16 bronze statues – including the 12 apostles – were airlifted to safety ahead of planned building work.

Irreplaceable roof
After the fire began in the attic, around two-thirds of the 800-year-old oak beams that made up the rooftop burned to ashes.

Flying buttresses
These icons of the east façade were an afterthought added in the 13th century, but may have helped support the structure as the inferno raged.

Rose windows
While it was feared the fire would melt the famous 13th-century stained-glass windows, all three survived.

Vaulted stone ceiling
While the carved ceiling likely shielded the interior from harm, it also stopped firefighters from being able to shoot water into the attic from the ground.

Saving grace
Despite the spire collapsing, the altar, pews and chancel windows in the eastern end of the cathedral remained intact.

Upper windows
While the rose windows survived, less famous frames nearer the rooftop were not so lucky, including one between the towers and another on the south side.

The rise, fall and resurrection of Notre-Dame

1163
FOUNDING FATHER
The cathedral's first stone is laid on Paris's Île de la Cité, with Pope Alexander III attending the ceremony.

1185
CALL TO ARMS
Heraclius, archbishop of Caesarea, calls for the Third Crusade from the still-unfinished cathedral.

1431
CROWNING ACHIEVEMENT
During the Hundred Years' War, ten-year-old Henry VI of England is also proclaimed ruler of France in Notre-Dame Cathedral.

1548
RELIGIOUS RIOTING
Rioting French Protestants – known as Huguenots – damage some of the statues in the Catholic cathedral.

1793
OFF WITH THEIR HEADS
Mobs loot the cathedral during the French Revolution and even decapitate 28 statues of biblical kings in a mock execution.

1804
ALL HAIL NAPOLEON
In a lavish ceremony at the cathedral, watched by a cheering crowd, Napoleon crowns himself emperor of the French.

1844
NOVEL COMEBACK
The popularity of Victor Hugo's *The Hunchback of Notre-Dame* prompts a major restoration of the cathedral.

1871
PARIS IS BURNING
During the Paris Commune insurrection, Notre-Dame is set alight, but it doesn't cause lasting damage.

1914
THE SKY IS FALLING
WWI sees the rise of aerial bombing, but Notre-Dame survives relatively unscathed – except for a hole in the roof.

Inside Portugal's Pena Palace

Nestled atop a hill, this kingly home is a real-life fairytale castle in the clouds

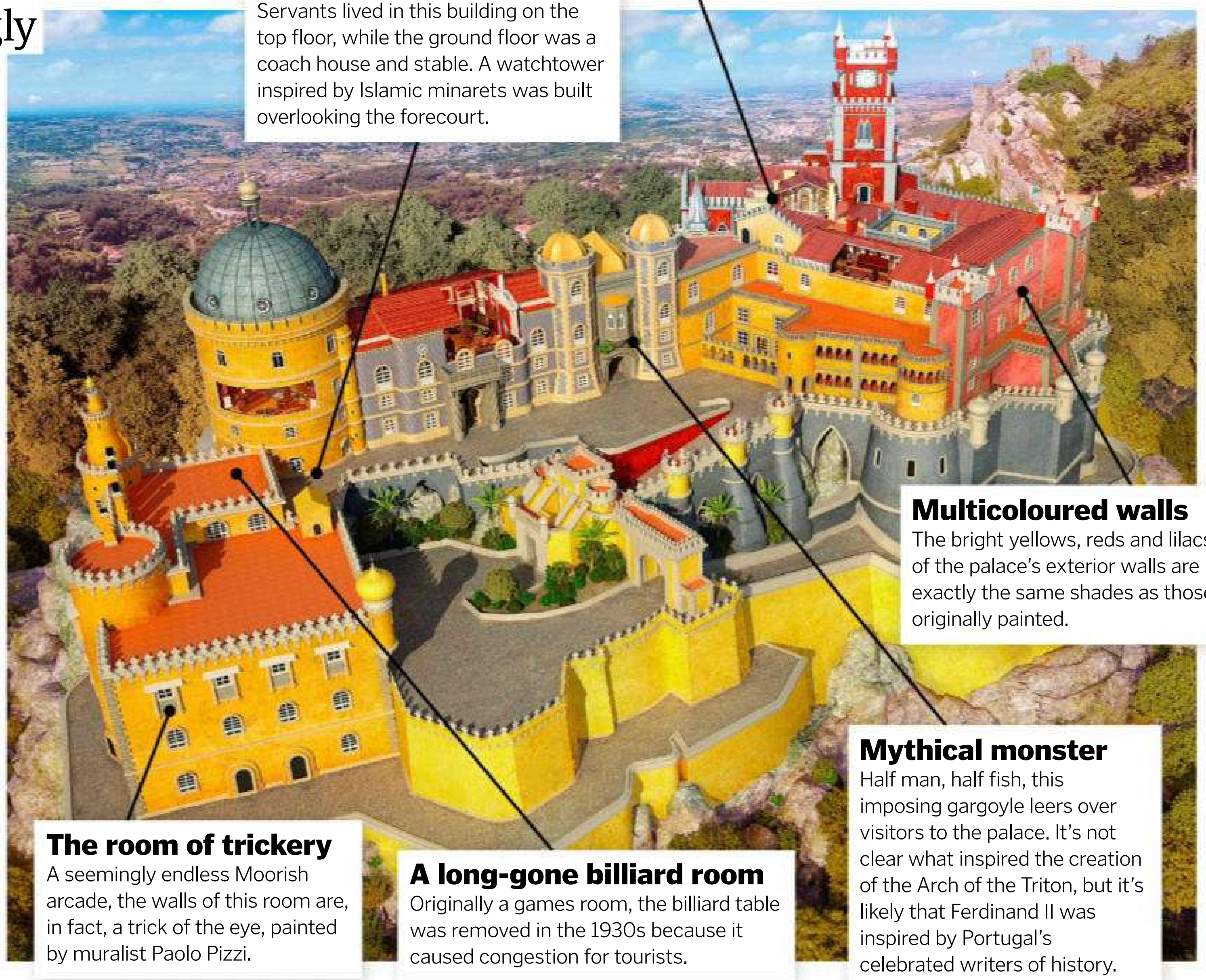
An hour outside of Lisbon lies Sintra National Park. Tucked unobtrusively between its slopes stand some of Portugal's most exquisite royal residences, including the Moors Castle, Monserrate Palace and Quinta da Regaleira. But none capture the imagination like the National Palace of Pena, a castle built on the top of one of Sintra's hills by Portugal's king of culture.

Having married Queen Maria II of Portugal in 1836, Ferdinand II was granted the title 'king consort' once their firstborn son arrived in 1837. In 1838 he bought the monastic ruin of Pena. Here he could realise his dream of a rural retreat from courtly life – a palace blending the old Moorish style with the new Romantic fashion.

Over 15 years the palace was built, but in 1853 tragedy struck. Maria died giving birth, leaving her 16-year-old son and heir as king. Ferdinand acted as regent for his son, but as a foreigner he was regarded with suspicion. As his son took on more royal responsibility, Ferdinand devoted himself to his passion project, spending his final years there.

Secrets of the palace

Uncover the hidden jewels of Ferdinand II's royal retreat



© Getty

The National Palace of Pena sits like a crown above the Portuguese landscape

What was the Portuguese revolution?

In the wake of Ferdinand's death in 1885, the National Palace of Pena passed from hand to hand, initially bequeathed to the king's second wife, the countess of Edla. However, Luís I, Ferdinand's son from his first marriage to Queen Maria II and the king of Portugal, was appalled that the palace had fallen out of royal ownership. At his insistence, the government wrangled to reclaim the residence, succeeding in 1890.

But the success was shortlived. A series of catastrophic blunders from 1890 into the 1900s left the monarchy in turmoil. In 1908 national discontent was at an all-time high when King Carlos I and his heir, Prince Luís Filipe, were shot dead in Lisbon. 18-year-old Manuel II ascended the throne, but the damage was done – after a reign of two years, defined by political unrest and revolts, the young king abdicated and fled into exile, leaving all his kingly belongings to the newly founded republic.

Of the royal palaces, some were left abandoned, others were saved as monuments, and the official residence of the last king, Necessidades Palace, was shelled. Pena Palace opened as a museum in 1911.

The Lisbon Regicide of 1908 left Portugal with an 18-year-old as king

A royal passion project

12th century
The first record of a building on the site is made, revealing that it is a chapel devoted to Our Lady of Pena.

1755
The Great Lisbon Earthquake crumbles the capital and triggers a devastating tsunami. Miraculously the monastery's chapel manages to survive.

1834
Portugal's dissolution of the monasteries means the old monastery at Pena is handed over to the government, and the monastery ceases to exist.

1838
Having fallen in love with the monastic ruin, Ferdinand II buys the site from the state with his own money.

1839–54
Over 15 years Ferdinand builds the palace in his vision, renovating the monastic ruins and eventually building new palatial quarters on the site.

1885–89
After Ferdinand's death the palace is bequeathed to his second wife, the countess of Edla, then sold back to the royal family and later the state.

1911
After the bloody overthrow of the Portuguese monarchy, the new republic declares the palace a national monument, and it opens as a museum.

1995
The town of Sintra and its landscape – including the National Palace of Pena – are declared a UNESCO World Heritage Site.

© Illustration by Nicholas Forder

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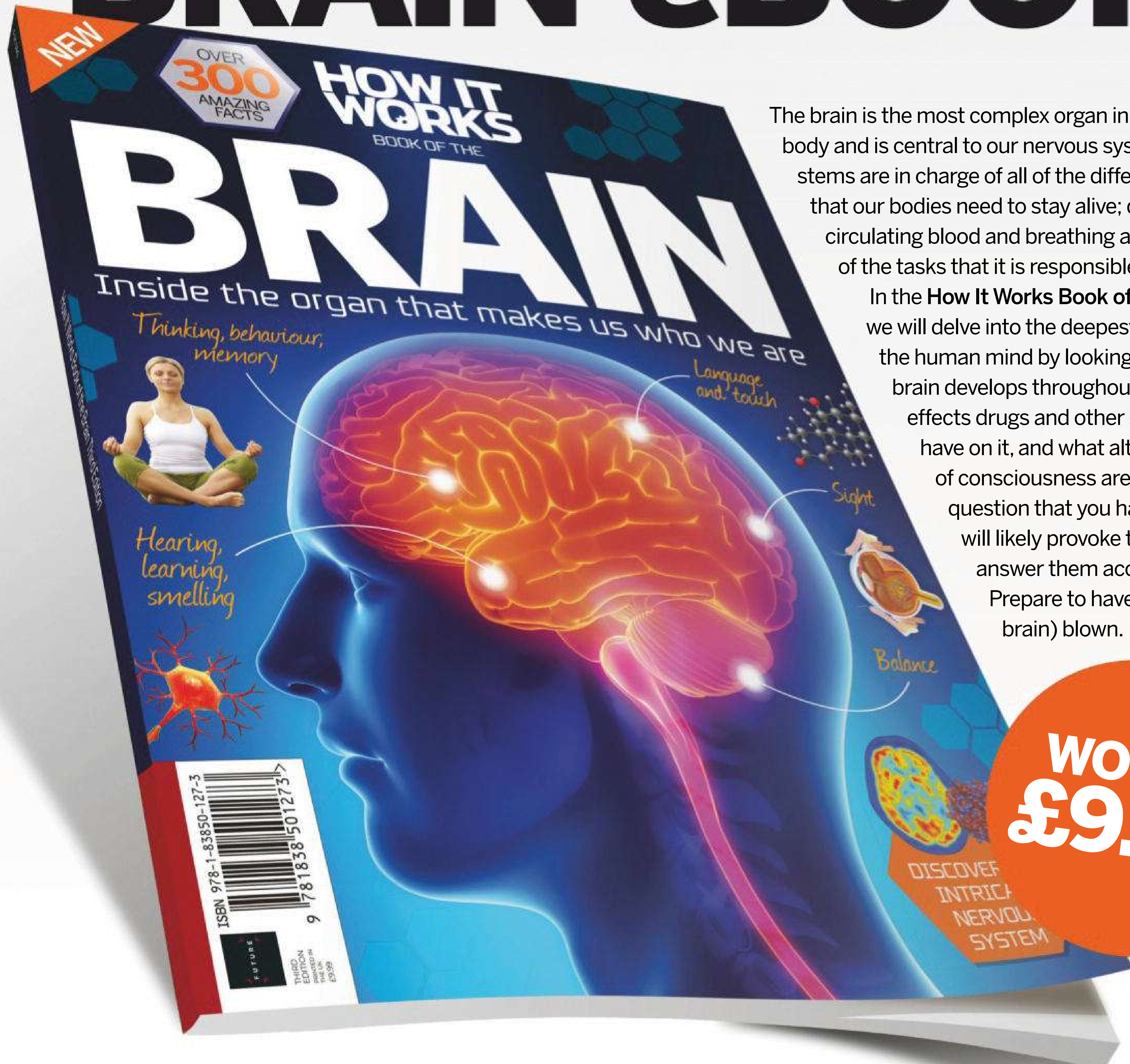
BOOK OF THE BRAIN eBOOK



The brain is the most complex organ in the human body and is central to our nervous system. Our brain stems are in charge of all of the different functions that our bodies need to stay alive; digesting food, circulating blood and breathing air are just some of the tasks that it is responsible for.

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CREATING MOVIE MAGIC

Discover how the cinema is brought to life with computer-generated visual effects

Words by **Scott Dutfield**

Whether it's an explosion behind James Bond, the spellbinding sparks of Doctor Strange or Will Smith's genie makeover in *Aladdin*, visual effects play a vital role in conjuring movie magic. Ditching the days of rubber-faced monsters and visible strings, today's cinema is bursting with the best that visual effects has to offer.

There are two ways in which movie magic can be cast upon a film – as either a special or visual effect. Special effects are typically those achieved on the physical movie set, such as explosions and animatronics, whereas visual effects (VFX) are applied with computer programmes after filming a scene, in the post-production stage. Using key techniques, VFX can range from simply changing the light to reflect the time of day, to bringing to life a fantastical world drawn from an artist's imagination.

Helicopters can be transported to any location with the help of a green screen

© Outpost

Behind the green screen

The green screen is an iconic part of visual effects in movies, and is also used in TV weather forecasts. Adding VFX via this method is known as 'keying', where artists replace sections of footage with different footage or computer-generated models, for example.

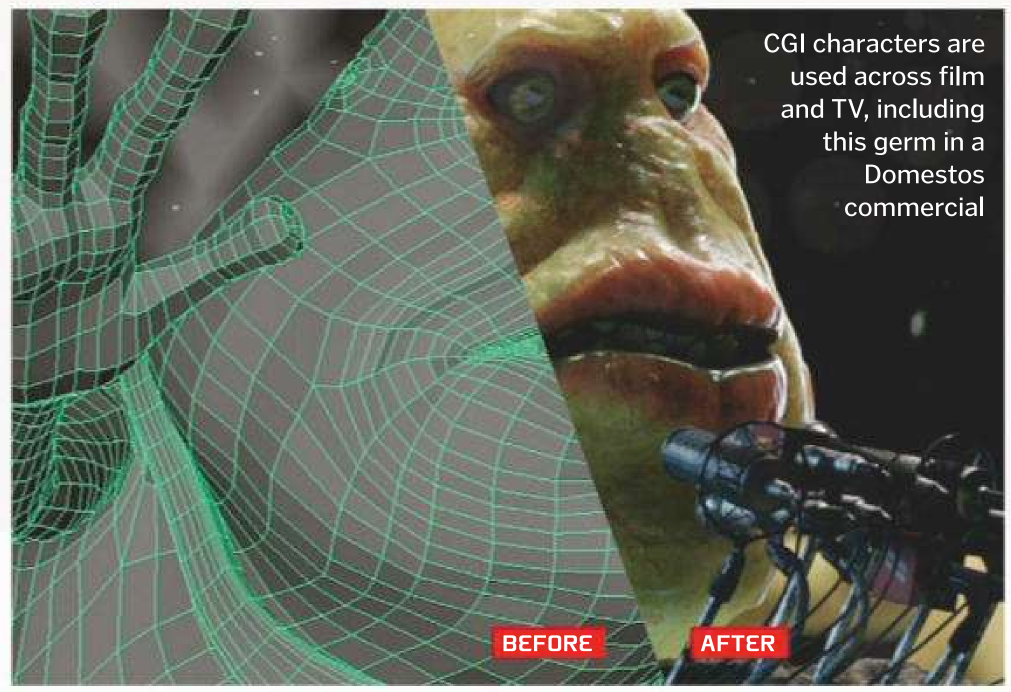
This is achieved by telling design software to remove a certain colour from footage, typically green or blue (depending on the screen colour) and replacing it with VFX elements. Actors in the scene can't wear that colour or their clothes and bodies would vanish into the background. Keying is used to digitally create surroundings that may be too dangerous or unobtainable in real life, or have simply been plucked from an artist's imagination.

Creating a CGI cast

Computer-generated imagery (CGI) is a way to put any digital creation a designer can imagine into a scene. Creating a three-dimensional CGI model can involve a digital version of clay sculpting. From concept art to digitally carving the final creation, CGI can achieve the impossible.

After compiling a series of computer-generated graphics, the final model is then textured, coloured and lighted, keeping in tone with the aesthetics of the movie. For a CGI model to then be animated, each limb, for example, is digitally linked together, almost like adding artificial tendons beneath the model's outer appearance. Known as rigging, this process then allows animators to take the designed model and puppeteer it in a scene.

Although animated, there are different considerations during the production of a CGI character in a live-action movie compared to a full-length animation film. Any CGI creation plays a role within a film, so human actors must interact with their environment on set as if the CGI character is there, while conversely the CGI characters must be puppeteered in a way to give the illusion it's reacting to the actors too.



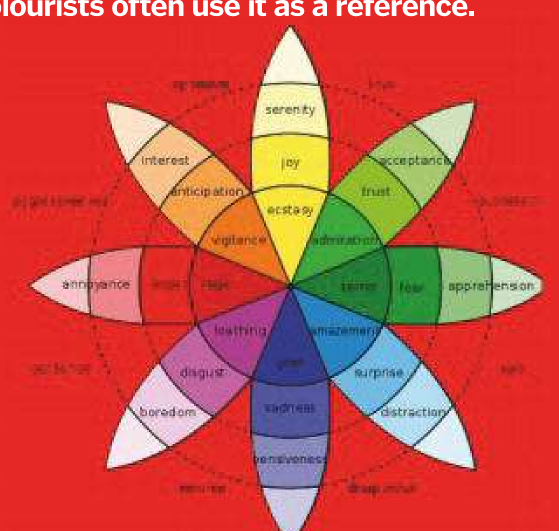
CGI characters are used across film and TV, including this germ in a Domestos commercial

© Outpost

'Feeling' colours

Numerous VFX artists and creators will work on a single feature film or TV show. One artistic arm of the production body is the colourists. Tasked with maintaining colour cohesion, saturation, vibrancy and tone, a colourist can manipulate the way an audience emotionally responds.

Colours are often associated with emotions. By identifying what emotion the film makers want, a colourist can highlight a colour or shade to promote that feeling. This emotion and colour relationship was outlined by psychologist Robert Plutchik, who created the Plutchik colour wheel of emotions. Colourists often use it as a reference.



Engulfed in particle-effect flames, Smaug from *The Hobbit: The Battle of the Five Armies*

© Alamy

Smoke and fire

Smoke, fire or water can pose a problem for VFX artists. Impractical to digitally hand-draw or sculpt, artists use particle effects software like Houdini to realise their designs. Designers generate thousands of points, or particles, within the software, and by dictating each particle's movement, size, shape and colour, the simulation of a fire, sandstorm or a waterfall can be created from scratch.

Much like the creation of a CGI character, particle effects require the artist to define the way each particle moves, to mimic the natural movement of what they are trying to recreate, such as the fluid motion of water.

Cleaning up imperfections

It may seem as though current cinema has moved far beyond the use of strings to suspend flying objects, but in fact movie makers have just got better at scrubbing them off the screen.

Rotoscoping is a method used to isolate part of a frame and either remove or relocate it. By marking the outer parameters of an object, VFX artists are able to cut and paste footage frame by frame. For example, in any science fiction film scene in which a character is experiencing zero gravity (when in real life they are suspended on wires), scenes of their weightless motion can be cut out and pasted onto another background. This visual effect, however, is a time-consuming endeavour, as films are often shot at 24 frames a second.

The strings holding Jake Gyllenhaal in the antigravity thriller *Life* are easily removed with rotoscoping

© Outpost

VFX elements surrounding a moving character are tracked and follow the motion of the camera

© Outpost

"Combining the two exposed films resulted in a sequence that left audiences spellbound"

Seamless effects

Visual effects are only as effective as their ability to seamlessly integrate with a scene. Their value is directly tied to the audience's ability to believe that something computer-generated could really be interacting with live-action elements.

This is where tracking comes in handy. Tracking is the process in which all the VFX elements in a shot follow the movement of an object, person or the direction of the camera in the original footage. If the movements of the added VFX elements are not in sync with the movement of the camera, the combination of the two feels disjointed, and the desired illusion is broken.

The magic of Méliès

The art of visual effects is not a concept new to the 21st century, nor the 20th. In the late 1800s magician and future film revolutionary Georges Méliès put the wheels in motion for visual effects. Long before the use of green screen keying, Méliès created a technique known as 'matte' to composite different footage.

In his 1898 silent film *The Four Troublesome Heads* (*Un Homme De Tête*) Méliès appears to take his head off his body and place it on a table, repeating the impossible feat three times. In this original trick of early film, Méliès used a pane of glass painted with a black matte finish to block out his head. Rewinding the film, he then placed matte black over everything other than his head. Combining the two exposed films resulted in a sequence that left audiences spellbound.


© Alamy

Georges Méliès used pioneering techniques to create spectacular illusions on film

© Outpost

DID YOU KNOW? In *Avengers: Infinity War* there are 2,680 VFX shots, 253 of which are in the opening act

Piecing the puzzle together

This is the process whereby all of the VFX elements are brought together. Like a digital jigsaw, each effect and film footage can layer over one another, known as compositing. This process can be as straightforward as dropping in a new background, while in heavy VFX scenes several elements need to be compiled and composited, creating several layers to form the final product.

Dissecting a scene

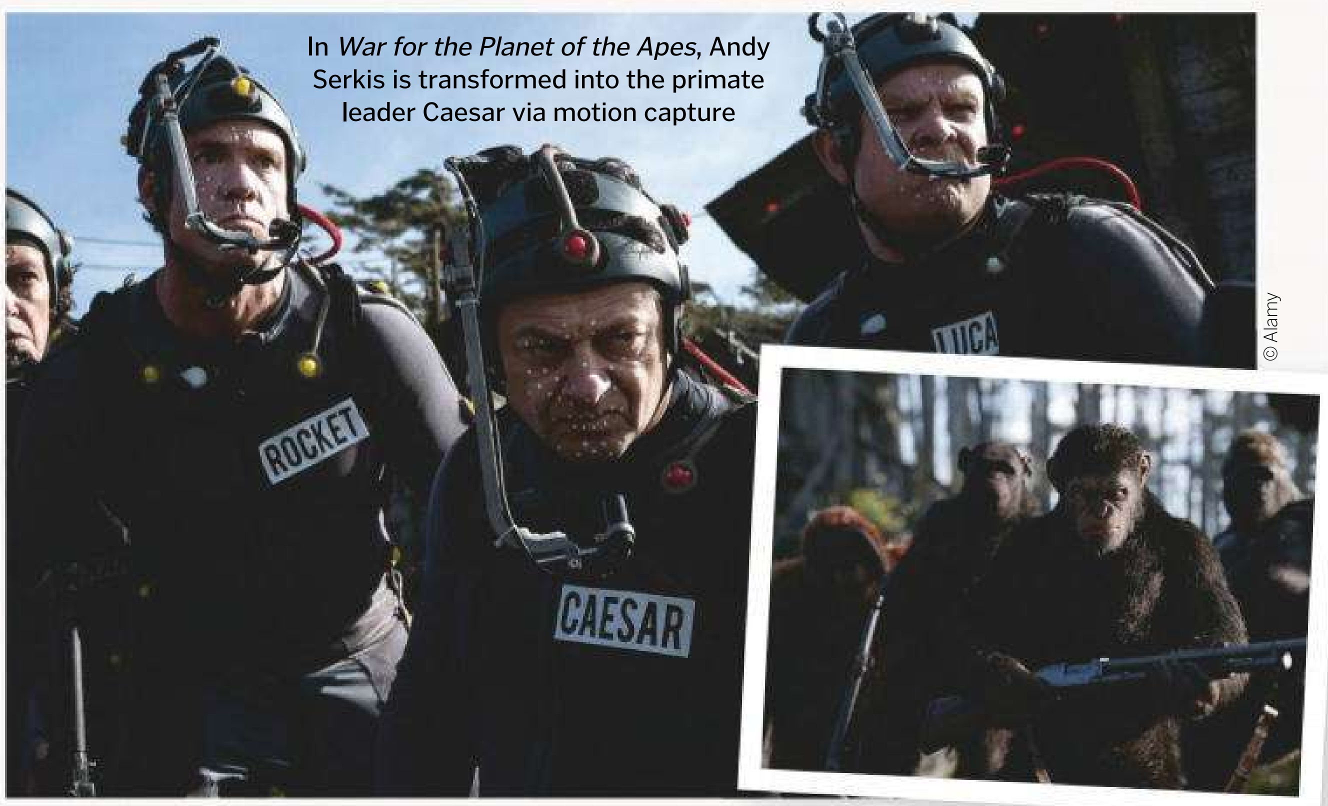
Frame by frame, how VFX experts fill a single scene with different visual effects

Body swapping

Motion capture brought to life characters such as the inhabitants of Pandora in *Avatar* and the beast from *Beauty and the Beast*. Combining real life and the digital world, three-dimensional motion capture transforms actors into their computer-generated characters.

To make this transformation, actors wear a capture suit covered in small dots. These dots, known as tracking position markers, act as reference points to track the actor during a scene. In the VFX process, these points can be mapped onto the virtual skeleton of a computer-generated character, such as Gollum from *The Lord of the Rings*.

Digitally stitching both the real-life actor to their CGI character, the two appear as one on screen. Motion capture can also be used to add VFX to separate areas of the body, such as the hands or face, rather than the entire body.



In *War for the Planet of the Apes*, Andy Serkis is transformed into the primate leader Caesar via motion capture

Visual effects through the years

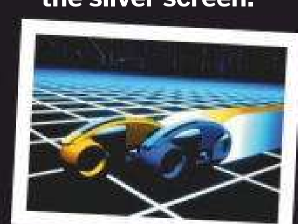
Here are some key moments in the history of movie visual effects

1973
In Michael Crichton's *Westworld* the lead character's 'robovision' is the first example of 2D CGI.

1976
The first 3D computer graphics are found in *Westworld*'s sequel, *Futureworld*. The main android's head and hands are digitally created.

1977
The Death Star attack briefing scene in *Star Wars IV* sees the first example of 3D wireframe graphics.

1982
In *Tron*, the light cycle races were the first extensive 3D CGI sequences seen on the silver screen.



1985
Combining digital and live action, Pixar's *Young Sherlock Holmes* creates a stained glass warrior that leaps straight from the window to the ground.

1989
The first example of CGI water effects appears in *The Abyss* in the form of a morphing sea monster.

Q&A
Marcin Kolendo

Now a senior VFX supervisor at Outpost VFX, Marcin Kolendo has previously worked on films such as *Jason Bourne*, *Les Misérables* and *The Snowman*

© outpost

What is the journey from unedited footage to the final product?
We get involved, from time to time, at the very beginning of the production, getting a script and making sure everything is arranged from our side. Then during the shoot, we are involved in supervising for visual effects on set, basically making sure every box is ticked and things are going smoothly, to keep everything on budget for the client.

Then we get the footage. This comes in a raw state. Our company is divided into many departments, working closely together and working at the same time on the same projects. So firstly the editorial team converts the raw footage into a usable format for the artists to open and commence work on. After editorial – let's say we have shots that require a lot of cleanup, for example: [maybe] the project is a period drama and there is some sort of unexpected surprise, like an aeroplane for example, needs to be removed. When that's done, the same shots are picked up by senior artists, who will drive it to the final product.

How long does it usually take to add VFX to a single scene?
It depends on the length of the shot, from action to the cut of the camera. We have had shots that are less than ten frames long, which is less than a second, and we've had shots that are over a minute long, so they are mammoth tasks to fit anything in.

It can depend on the complexity of the shot. It could be a very long shot but the requirement is to only remove a microphone that's popped into the frame. Or it can be 20 frames, around a second long, that's full-on CGI, with monster, fires and explosions, which can take months even though it's just a second of the film.

What are the biggest challenges in VFX?
I think it's to get on the same creative level as the clients, that's the very first thing I'm looking for. Getting to know the show or project as much as you can and read about the story and background – if it's a period drama, for example.

> "It can take months even though it's just a second of the film"

Another big challenge I think is the deadline [that we're] given, and how much time we can spend on set. It's not that we have one or two shots on the project – we can get 200 shots on the project sometimes, or we are getting an entire project ourselves with 500 shots to do in a month's time. So that needs to be planned, and we are always reaching for the very best quality possible.

What do you enjoy most about your work?
I remember getting comments on some of the footage that we produced, [saying] that there were no visual effects in this particular movie – yet there were loads in every shot! That's the best compliment we can get as a company and for myself as a supervisor. As long as everything that's sitting within a shot and a scene or sequence is seamless, then I did a good job, and I think that's the most rewarding.

What's been one of your favourite projects to work on?
I think the most rewarding for me was *Jason Bourne*. That could have been because I was working with director Paul Greengrass and I was with him on *Bourne Ultimatum* back in my previous company in London. That was one of my favourite projects, partly because it was completely invisible visual effects, and also because the films are good and energetic.

What project would you have liked to have worked on that you didn't?
Most of the people from visual effects would say it's the *Star Wars* films. When I started doing visual effects it became apparent to me that I wanted to get involved in epic films, more deep films, like *Blade Runner* or *Interstellar*.

1995
Pixar's ***Toy Story*** is the first full-length computer-generated film.

1997
James Cameron's ***Titanic*** showcases some of the most extensive VFX of its time, featuring over 500 visual effects shots.

1999
Iconic for its gravity-defying stunts, VFX artists on ***The Matrix*** create the first slow-motion bullet-time effect.

2001
The first CGI creation that resembles a real human is seen in CGI character Doctor Aki Ross in the sci-fi movie ***Final Fantasy***.

2004
Motion-capture comes to life for the first time in Robert Zemeckis's movie ***The Polar Express***.

2009
Avatar is revolutionary in its facial capture effects, grafting the voice actors' faces onto their animated counterparts.

The super-powerful MAREA cable, which weighs more than 30 blue whales combined, comes ashore

How deep-sea cables are laid

It's a serious undertaking to connect each country to the internet across thousands of kilometres of ocean

We often think we're living in an increasingly wireless world. We store our data in the cloud and view it on mobile devices that we can carry around in our pockets. But phone masts that give us 4G signal are just the tip of the internet iceberg. More than 95 per cent of international web traffic is actually carried by undersea cables.

Currently there are approximately 378 of these telecommunication tentacles crisscrossing the seafloor. With a combined length of roughly 1.2 million kilometres, they link the US to Europe, France to India and more. In fact, they connect every continent except Antarctica.

Submarine cables aren't new. Samuel Morse, who developed the telegraph, successfully sent his dots and dashes via New York Harbor in 1842. But it was the UK that saw the potential in this technology, using it to connect its vast colonial empire. The first transcontinental cable linked Ireland to Newfoundland in 1858. Within 14 years, London could send a message to New Zealand via Bombay, Singapore and China. In 1892 British companies controlled two-thirds of the telegraph networks worldwide.

While the telegraph is no more, undersea cables have not only survived but thrived. The earliest intercontinental line could only send a few words an hour. But in February 2019 the MAREA cable, stretching almost 6,500 kilometres from Virginia Beach in the US to Bilbao, Spain, successfully generated signal speeds of 26.2 terabits per second. That's like streaming 7 million HD movies at once. This is thanks to fibre optic cables.

Carrying pulses of light fired by powerful lasers, which can then be decoded as data, these cutting-edge cables send information at incredible speed. Today companies like Google, Facebook and Amazon are spending billions of dollars on infrastructure to boost their bandwidth, by laying their own fibre optic cables across the world's oceans.

The size of Microsoft's and Facebook's coiled Marea cable gives you a sense of how long they can be

Fixing broken cables underwater

Atlantic cables require more than 50 repairs a year due to damage from ships, earthquakes and wildlife. A malfunctioning optical fibre will bounce back the light pulses it's supposed to be sending across the ocean. By measuring how long it takes for the signal to return, engineers can tell where on the cable they have a problem. A repair ship is then dispatched.

ROVs (remotely operated vehicles) haul the cable to the surface for repair. These robots then bury the fixed cables back under the seabed using high-pressure water jets. Grapnels can also be used.

Fixing a cable is a long job. It can take ten or so days, with four to five days spent at the location of the break. It takes around 16 hours for a skilled technician to intertwine the glass fibres and attach the new section of cable to each cut end of the original.

Just as this ROV maintains an underwater oil mine, robots help fix cables deep under the sea

Super-secure connection

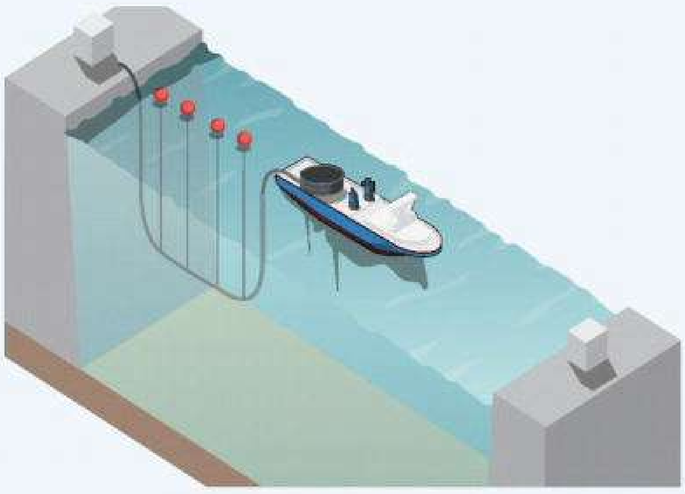
At either end of every undersea cable you will find a landing station. As well as acting as a go-to for the terrestrial networks we all use, these stations carry out important jobs. Between 3,000 to 10,000 volts are funnelled through a landing station to each cable to help them send data over vast distances. Underwater amplifiers boost this current every 100 kilometres. The stations also monitor their cables to make sure they're working right.

It's perhaps no surprise that these landing stations are carefully protected. Their exact location is often kept secret, and fingerprint scanners stop you from reaching their inner sanctum.

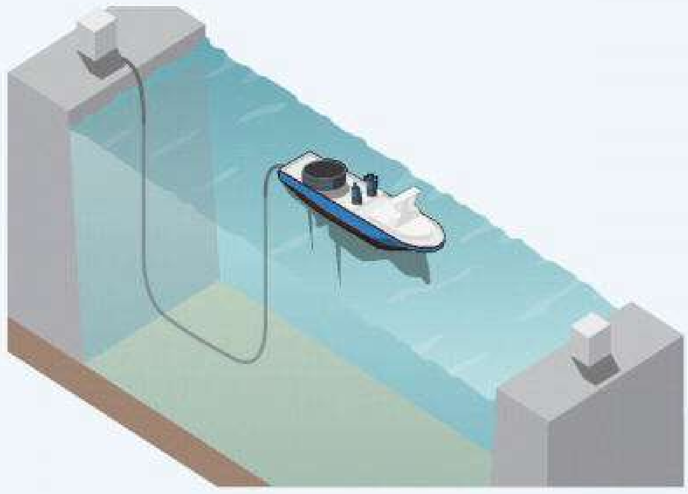
A landing point in Bangladesh, which connects the SEA-ME-WE 4 cable from France to Singapore

Laying cable

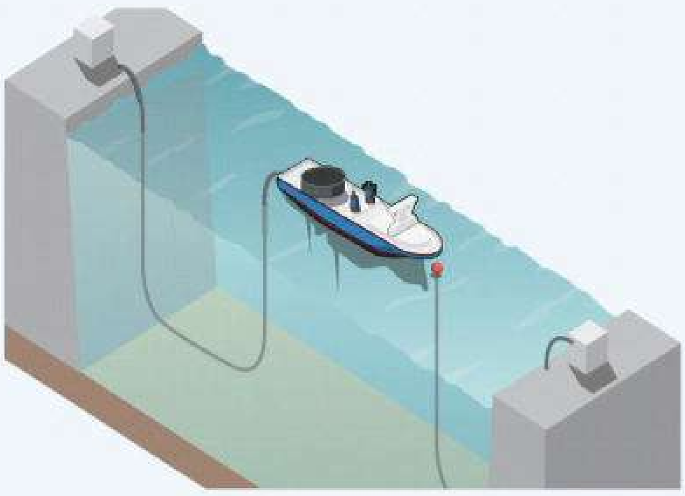
Get to the bottom of how data cables are laid on the ocean floor



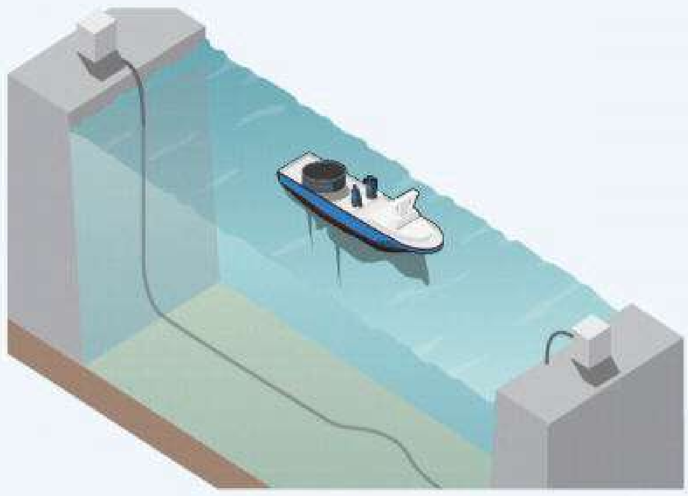
1 Setting sail
A ship trails a vast length of cable from a landing station out to sea, while balloon buoys prevent the cable from being damaged or sinking.



2 Good-buoy!
As the cable ship gets further out to sea, the buoys are removed and the cable sinks below the water.



3 A long voyage
After travelling great distances to reach a second station or a designated point mid-ocean, the ship meets another cable.



4 Making connections
A specialist on-ship 'jointer' carefully splices the two together, then the conjoined cable is released and buried beneath the seafloor.

Shark attack

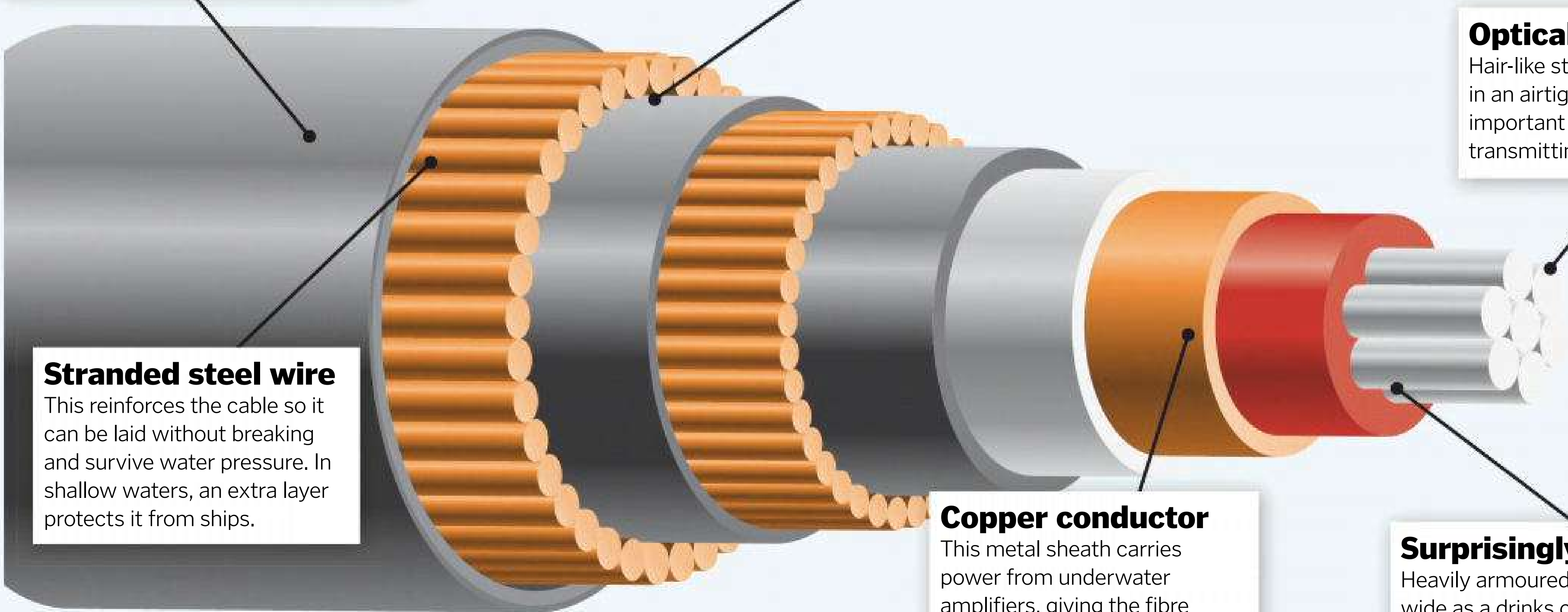
In 1985 engineers working in the Canary Islands, laying some of the first fibre optics underwater, had a problem. Their cables had failed four times in a row. After raising the broken line, they were shocked to find shark teeth in it. This wasn't an isolated case. There have been reports of barracudas, shallow and deep-water sharks chomping on cables worldwide. Why do they do it? It may be because they're attracted to the magnetic field, generated by the high voltage running through the cables. Sharks can detect even faint electrical signal with sensors in their snouts, which they use to hunt prey.

Google and other telecoms giants reinforce their cables with a Kevlar-like matting to protect against shark bites

Inside a submarine cable

How fibre optic cables are designed for deep waters

"The earliest intercontinental line could only send a few words an hour"



Outer casing
To protect against damage, cables are encased in polyethylene, a hard plastic also used to make water bottles.

Tar-soaked nylon yarn
Resembling a blackened bandage, this waterproof wrapping further protects the cable's internal components.

Optical fibre core
Hair-like strands of glass cushioned in an airtight jelly are the most important part of the cable, transmitting data as light pulses.

Stranded steel wire
This reinforces the cable so it can be laid without breaking and survive water pressure. In shallow waters, an extra layer protects it from ships.

Copper conductor
This metal sheath carries power from underwater amplifiers, giving the fibre optics an extra jolt to help send signals over long distances.

Surprisingly slim
Heavily armoured cables are about as wide as a drinks can. But at the deepest levels of the ocean, they're just 17mm in diameter – the size of a garden hose.

© Reaction Engines

HYPERSONIC AEROPLANES

Faster than Concorde, even quicker than fighter jets: these are the passenger planes of the future

Words by **James Horton**

© NASA

© Reaction Engines

© Sunil Gupta

No commercial service has travelled at supersonic speeds since Concorde was permanently grounded in 2003

SABRE engines could be included in future long-haul aircraft, ferrying people around the globe in just a few hours

© Reaction Engines

Since the Wright brothers first achieved powered flight in 1903, humankind's progress in the skies and beyond has been staggering. In the decades since, we've developed the jet engine and revolutionised global transport. We've cracked the sound barrier and flown our commercial and fighter jets at supersonic speeds. We've mastered rockets that have sent people to the Moon, rovers to Mars and satellites to orbit Earth before returning safely, ready to be used again. Yet remarkably a partnership between BAE Systems and Reaction Engines promises to propel us even further: enter the Synergetic Air-Breathing Rocket Engine, known as SABRE.

The beauty of the SABRE engine, once constructed, will be its one-size-fits-all design. All of the milestones listed above, in contrast, have relied on separate technologies to realise those goals. Air-utilising jet engines are perfect for getting a vehicle off the runway and into the sky and offer impressive manoeuvrability, but they are limited in how fast they can push an aircraft. Rockets, conversely, promise immense speeds but in exchange offer little control of the vehicle during its flight path; plus, they require huge amounts of fuel. The SABRE engine will be a hybrid design encompassing the best of both worlds – offering a vehicle that can take off as a jet, cruise the skies and launch itself into the expanse of space.

The development of SABRE promises to evolve more than just the aviation industry. With any new technology, improving our fundamental understanding helps to unlock answers to problems in other fields. As we'll further explore in this feature, the centrepiece of the SABRE engine is the precooling heat-exchanger, which can drastically cool moving particles, very quickly. The applications of this accomplishment could be incredibly wide-reaching. Imagine improved air conditioners and refrigerators, better heat recycling in road vehicles and enhanced cooling in nuclear power plants. Once the SABRE engine is powering the skies, it likely won't be long until its uses are also harnessed on the ground.

SABRE on Earth

Between the supersonic speeds of advanced jet engines and the Mach 18 offered by rocket engines is a hypersonic middle ground that represents a novel accomplishment for an 'air-breathing' craft. Thanks to the core technologies that are being developed to facilitate the hybrid design, SABRE-equipped vehicles will be able to reach these speeds within our atmosphere and zip around the world in a hurry. A joint project between Reaction Engines and the EU, dubbed LAPCAT, found that an aircraft powered by SABRE technology would travel from Brussels to Sydney in just over four hours when cruising at Mach 5. So get your sunscreen ready, as it could soon only take a morning to trade the frigid cold for a sun-drenched beach.

Speed of sound

What does it take to move through the atmosphere faster than a speeding bullet?

© Getty

SUBSONIC 0-980KPH

Mach number 0-0.8

Propeller vehicles, which includes both the turboprop plane and the helicopter variety, become airborne and cruise through the atmosphere at speeds well below the speed of sound.

© Getty

TRANSONIC 980-1,470KPH

Mach number 0.8-1.3

Transonic is a transitionary range where airflow over certain parts of a vehicle falls under the speed of sound, and on other parts goes over it during flight. Most commercial jets fall inside this bracket.

© Getty

SUPERSONIC 1,470-6,126KPH

Mach number 1.3-5

Supersonic vehicles break through the sound barrier, creating sonic booms as they fly. As air flows differently at these speeds, supersonic vehicles must be specially designed for high-speed travel.

© Reaction Engines

HYPERSONIC 6,126-12,251KPH

Mach number 5-10

Hypersonic aircraft encounter serious challenges with airflow, which is heated immensely at these velocities. Most current hypersonic aircraft rely on rockets with onboard oxidisers to reach these speeds.

© NASA

HIGH HYPERSONIC 12,251-30,626KPH

Mach number 10-25

Although rockets reach these speeds in space, they are incredibly difficult to reach within our atmosphere. At such velocities, friction from the air itself becomes extremely hazardous.

© Ktklin

RE-ENTRY >30,626

Mach number >25

The only way to reach these speeds within the atmosphere is by powering into space and returning to the planet. Only a thick, flat heat shield will allow a vehicle to slow sufficiently before it hits the ground.

Q&A

It really is rocket science

Chief engineer Richard Varvill gives us an update on SABRE's progress

Designing and constructing a SABRE engine demanded a slew of technological innovations. Which hurdle are you most proud to have overcome so far?
SABRE™ is based on existing gas turbine, rocket and ramjet technology. However, the precooler is novel to aerospace propulsion systems, comprising a very powerful and lightweight heat exchanger whose purpose is to cool the incoming air from Mach 5 recovered temperatures (1,000 degrees Celsius) to acceptable compressor inlet temperatures (around 100 degrees Celsius). Designing and building the precooler was a difficult challenge, particularly for a small company such as Reaction Engines. However, we were eventually successful, as evidenced by the cryogenic testing in 2012 and the current high-temperature testing in 2019 (at Test Facility 2 in Colorado).

What aspect of the engine design do you think is the most challenging moving forward?
The efficiency of the helium turbomachinery in the core air-breathing engine is challenging. As with any development programme for a new engine, ensuring high levels of durability of the rocket engine is a challenge we are working to address. The strategic investments we have received from BAE Systems, Rolls-Royce and Boeing (via its HorizonX venture arm) are proving invaluable in this process as these are all organisations with extensive expertise and experience in solving these types of development challenges.

SABRE engines may one day cater for many of our skyfaring and spacefaring needs. Which potential application excites you the most?
Cheap, reliable access to space is the most exciting SABRE application and the most deserving of a solution. Current space launchers are very expensive and are limiting mankind's ability to exploit the resources of space. The introduction of SABRE-powered launch vehicles will enable exciting future opportunities such as renewable baseload electricity from space solar power, space tourism, microgravity manufacturing, manned exploration of the solar system, asteroid mining and more.

© Reaction Engines

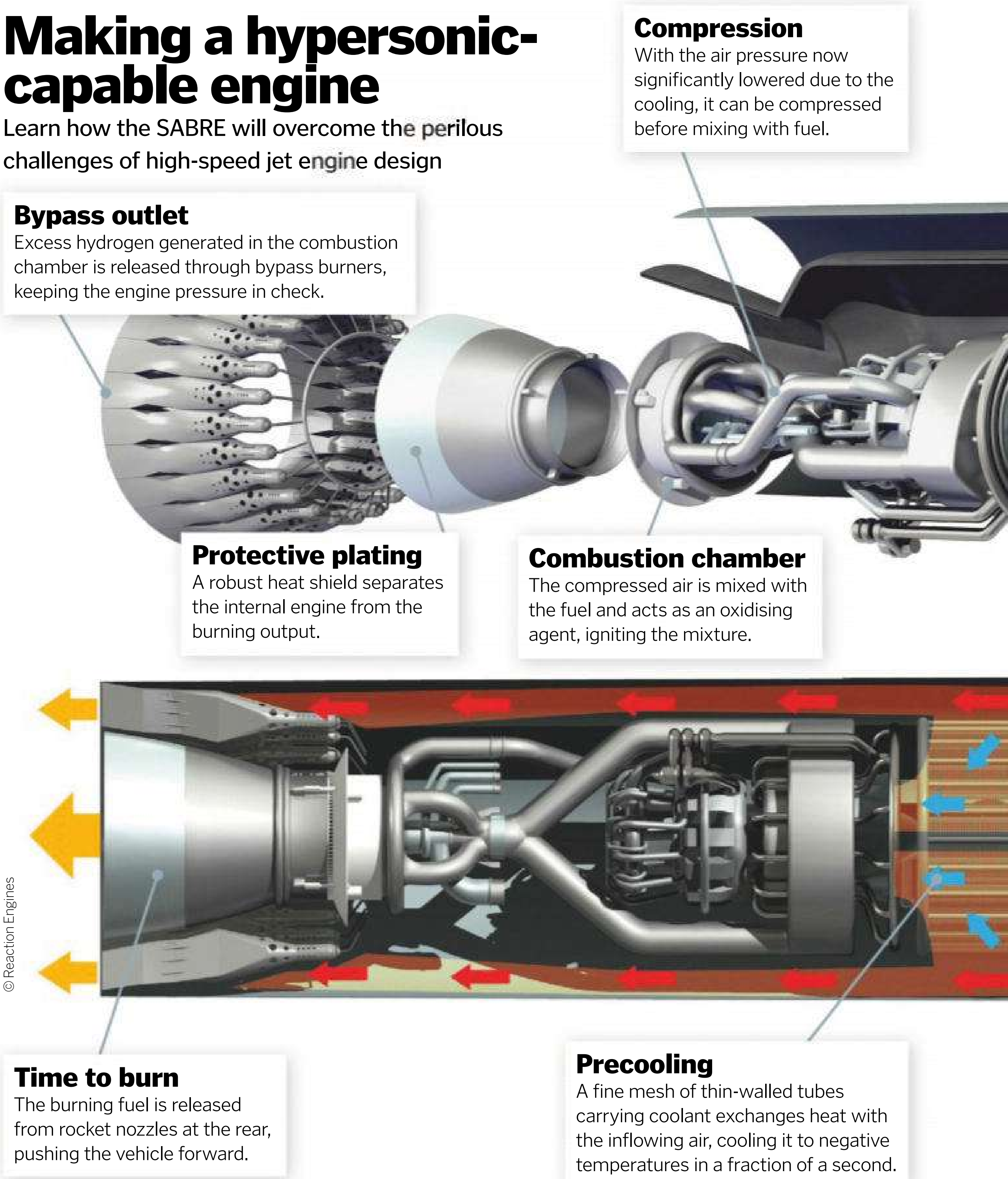
Richard Varvill

CTO, chief engineer and co-founder of Reaction Engines

Beginning his career in the Rolls-Royce Military Engine Division, Richard Varvill spent his formative engineering years designing air-breathing engines and winged launcher studies for the European Space Agency. He later co-conceptualised the SABRE engine and became a founding director at Reaction Engines.

Making a hypersonic-capable engine

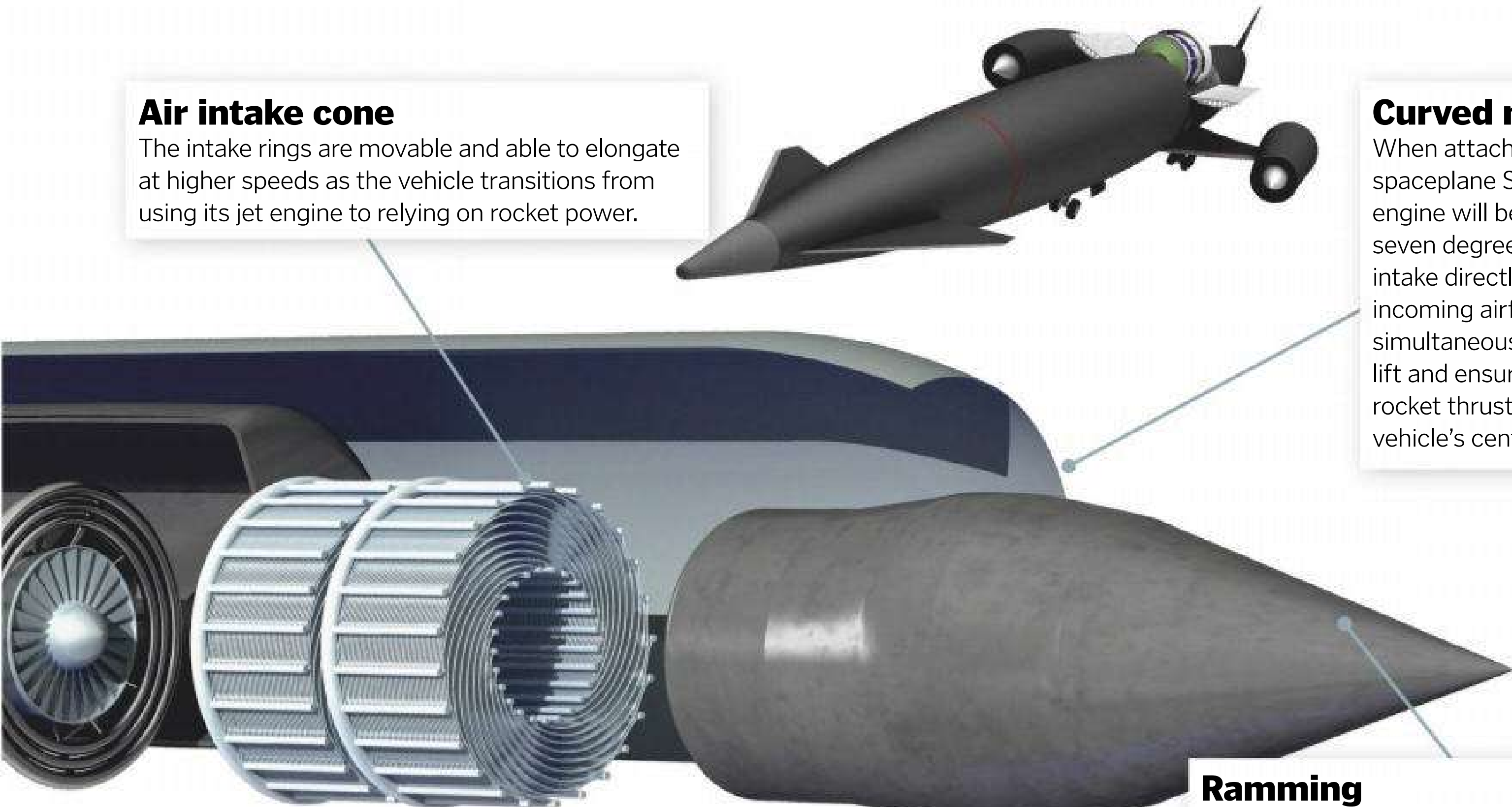
Learn how the SABRE will overcome the perilous challenges of high-speed jet engine design



© Reaction Engines

The ability to take off and land on a runway lowers the infrastructure requirements for a space launch

© Reaction Engines

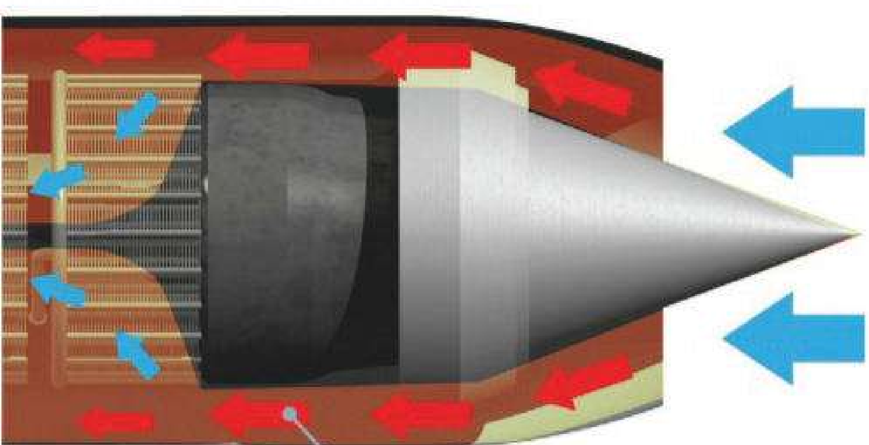


Air intake cone
The intake rings are movable and able to elongate at higher speeds as the vehicle transitions from using its jet engine to relying on rocket power.

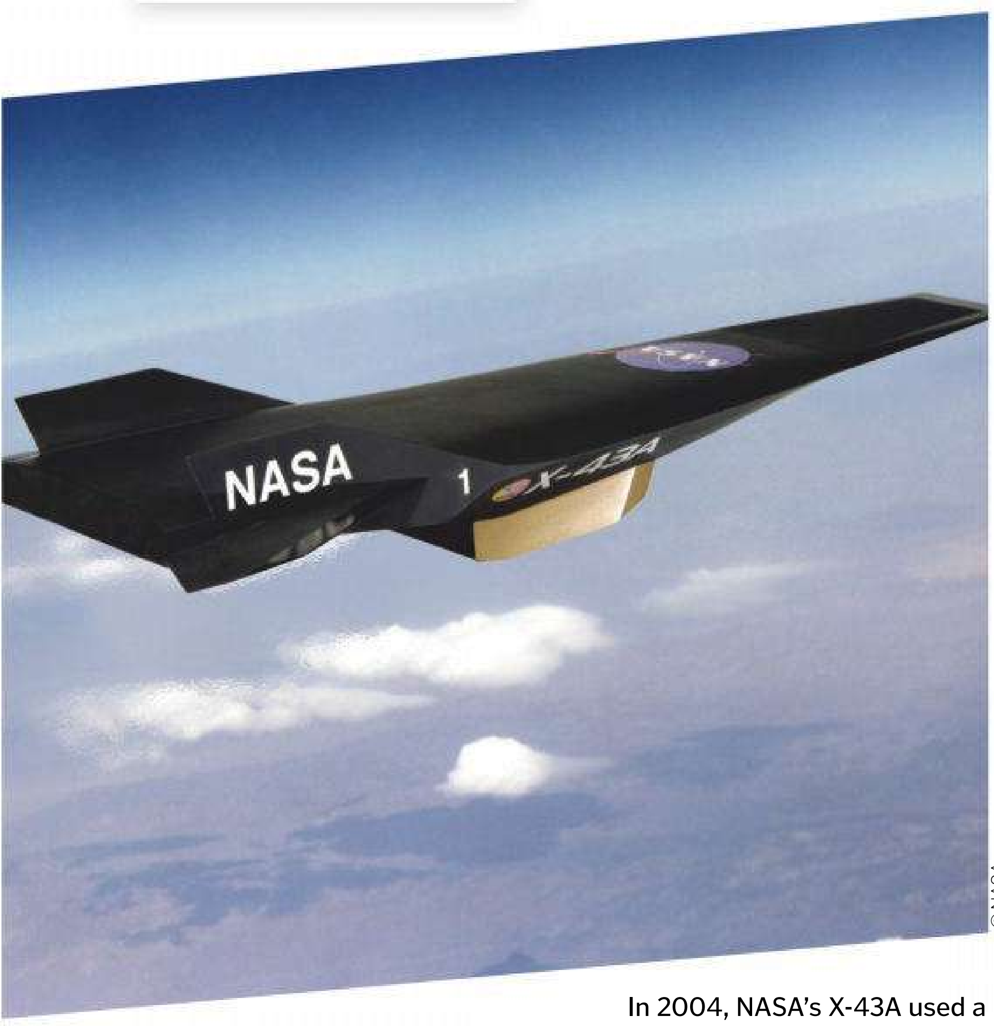
Curved nacelle
When attached to the spaceplane Skylon, the engine will be curved by seven degrees so that the intake directly faces the incoming airflow while simultaneously generating lift and ensuring that the rocket thrust matches the vehicle's centre of mass.

Ramming
Incoming air is 'rammed' into the vehicle at Mach 5 as the vehicle is travelling through the atmosphere so quickly.

© Illustration by Adrian Mann



Full of hot air
Air entering the engine at such high speeds inevitably warms to over 1,000 degrees Celsius.



© NASA

In 2004, NASA's X-43A used a 'scramjet' jet engine to fly at hypersonic speeds approaching Mach 10 under its own power

The Skylon spaceplane has been designed to deliver payloads into orbit using a SABRE engine

© Reaction Engines

SABRE in space

Space is fast becoming big business. Mining asteroids and building luxury resorts on the Moon may be in our future, but today the demand is for launching satellites into orbit around Earth. Climate analysis, GPS systems and wireless internet are all catered for by satellites, but getting these payloads to their destinations remains a major sticking point. SpaceX's renewable rocket design has shifted the landscape and made satellite delivery a much cheaper endeavour, but the SABRE designers at Reaction Engines aim to go a step further. They envision transforming the space industry into something resembling the aviation industry, where multiple contractors can own SABRE-equipped vehicles and repeatably and reliably launch payloads into orbit.

With the 'air-breathing' engine powering the vehicle to Mach 5 before the rockets are required, SABRE-powered craft will require less onboard oxidiser to power their ascent to space, reducing cost and increasing reusability. And by taking off and landing from a horizontal runway, the spacefaring vehicles will need far less sophisticated infrastructure to function, allowing many more companies to operate in orbit.

Inside the RRS Sir David Attenborough

The RRS Sir David Attenborough is built to withstand harsh environments

Countdown begins to the first mission of one of the world's most advanced research vessels

This July will see one of the most sophisticated floating research platforms ever built take to the sea.

Packed with state-of-the-art labs, testing facilities, research equipment and unmanned drones, the RRS Sir David Attenborough has been designed to uncover the mysteries of our polar regions, helping scientists research the oceans, atmosphere, sea beds and ice located at some of the most remote and inhospitable parts of the world.

Commissioned by the Natural Environment Research Council (NERC) in 2014, the vessel will be operated by the British Antarctic Survey, replacing its two existing ships – the RRS Ernest Shackleton and the RRS James Clark Ross, which are nearing the end of their lives in polar exploration.

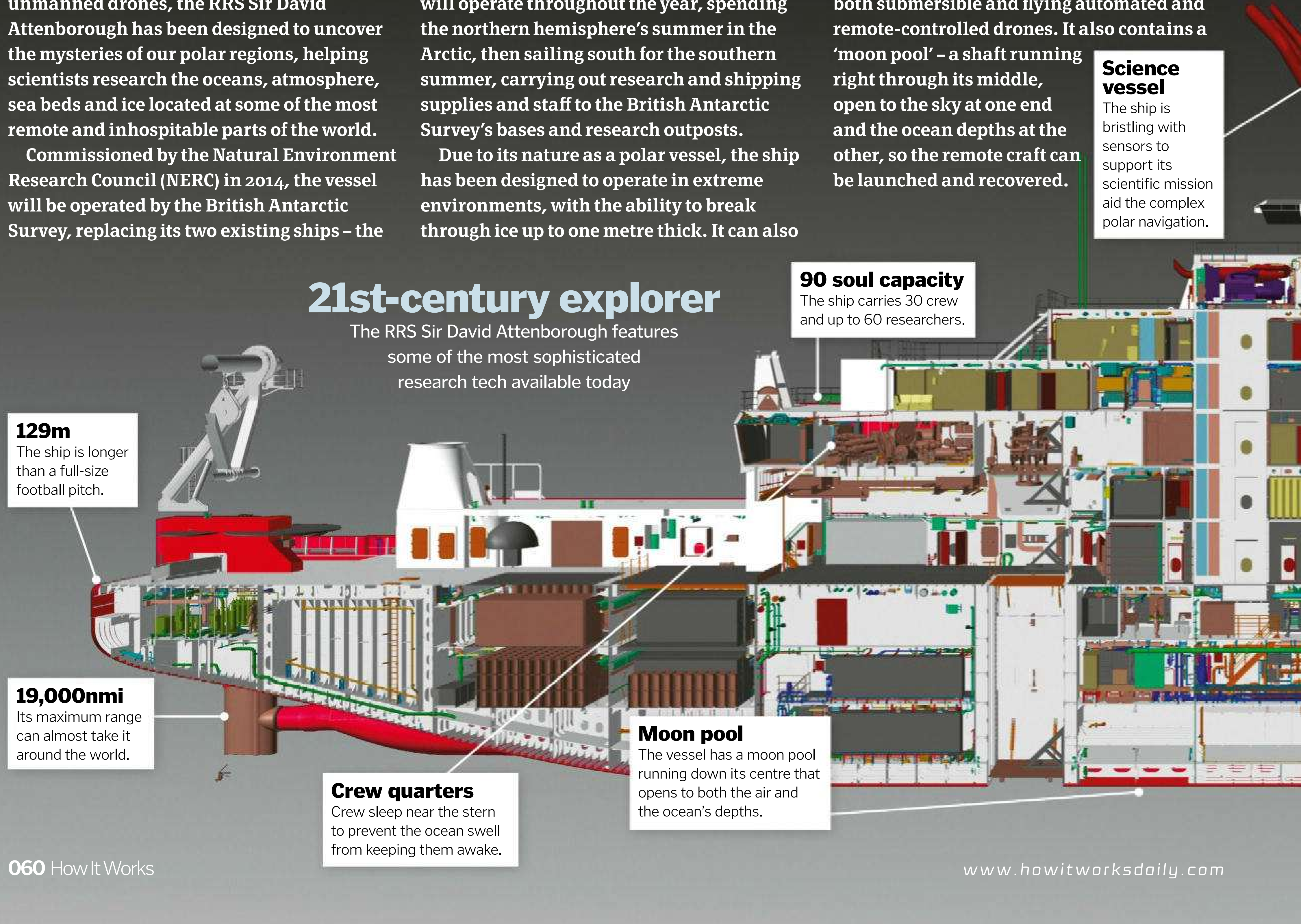
Named after legendary naturalist and broadcaster Sir David Attenborough, the ship will operate throughout the year, spending the northern hemisphere's summer in the Arctic, then sailing south for the southern summer, carrying out research and shipping supplies and staff to the British Antarctic Survey's bases and research outposts.

Due to its nature as a polar vessel, the ship has been designed to operate in extreme environments, with the ability to break through ice up to one metre thick. It can also carry enough fuel and food to remain at sea for up to 60 days at a time without needing to take on fresh supplies from support ships.

But it's in the scientific field that the ship is truly groundbreaking. It's equipped with both submersible and flying automated and remote-controlled drones. It also contains a 'moon pool' – a shaft running right through its middle, open to the sky at one end and the ocean depths at the other, so the remote craft can be launched and recovered.

21st-century explorer

The RRS Sir David Attenborough features some of the most sophisticated research tech available today



Environmentally friendly visitor

Of course, for a ship that's tasked with keeping an eye on the damage being done to our polar regions, the last thing its designers want is for it to become part of the problem.

To this end, the vessel has been designed with four main Rolls-Royce engines that operate on ultra-low-sulphur fuel, limiting its sulphur dioxide emissions.

The ship is also fitted with an oily bilge water separator that consists of a high-speed centrifuge to reduce the oil content of the bilge water discharged. Biodegradable oils have also been used wherever possible. It can also store its own sewage for up to 45 days when it's in parts of the world where even treated sewage discharge isn't allowed.


The Rolls-Royce engines powering the ship are enormous feats of engineering alone

Sir David Attenborough officially launches the ship with his name

Introducing Boaty McBoatface

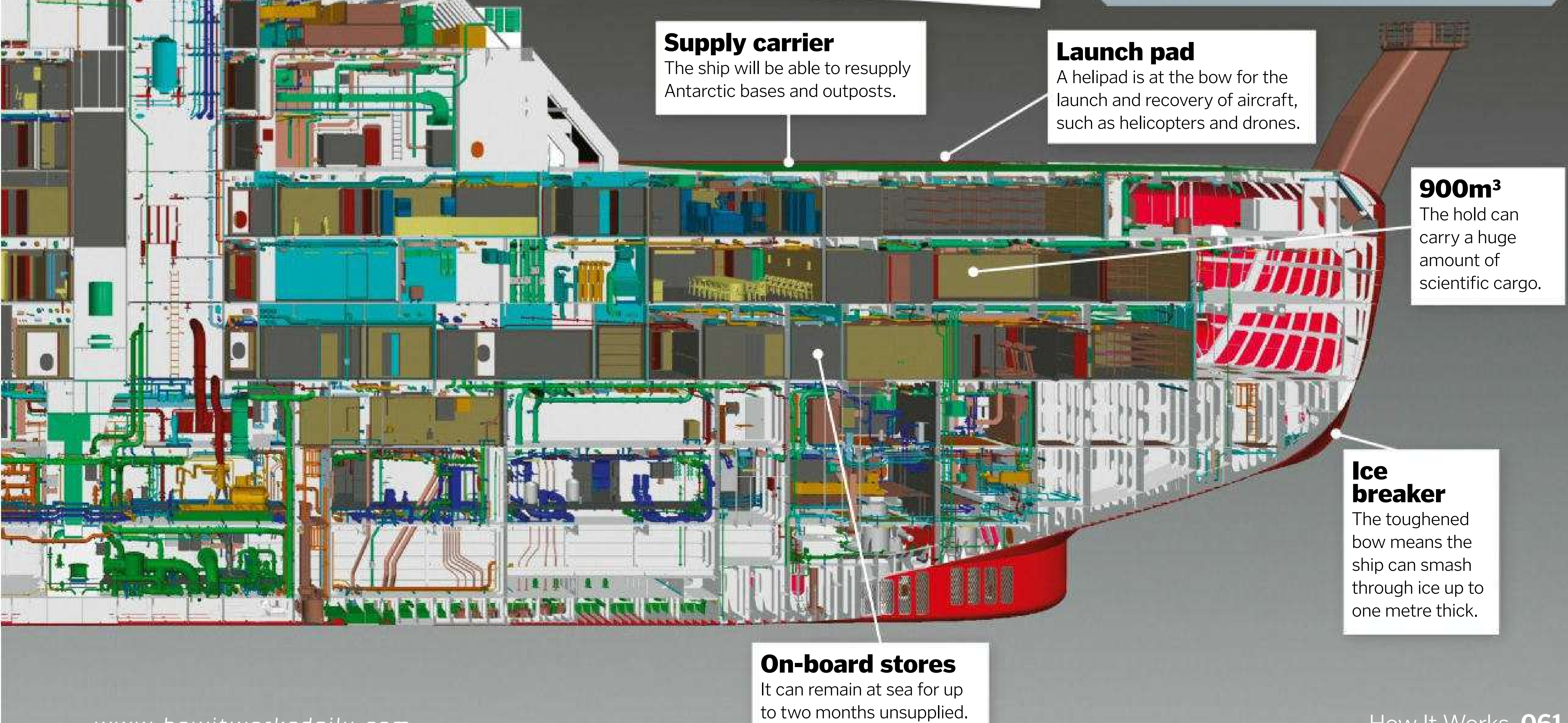
As a brand new research vessel designed for 2019 and beyond, the RRS Sir David Attenborough has been designed to act as a mother ship to a range of highly sophisticated remote and automated drones. One of these automated vessels is called Boaty McBoatface.

At just over 3.6 metres long, it's an 'autosub', an automated submersible that can travel for 2,000 kilometres on its own at depths of up to 6,000 metres.

One of three such marine robots carried by the mother ship, its ability to travel under ice for prolonged periods will enable it and its sister drones to explore up to 95 per cent of the ocean.

The autosub got its decidedly wacky name after the UK's Natural Environment Research Council conducted a poll to ask the public to name the ship itself (that would eventually be named the RSS Sir David Attenborough). Boaty McBoatface topped the results after it was suggested by a former BBC Radio Jersey presenter as a joke that backfired.


Boaty McBoatface is an unmanned submersible designed to explore beneath the ice



Control room
The vessel's 30 non-scientific crew keep it running smoothly.

Supply carrier
The ship will be able to resupply Antarctic bases and outposts.

Launch pad
A helipad is at the bow for the launch and recovery of aircraft, such as helicopters and drones.

900m³
The hold can carry a huge amount of scientific cargo.

Ice breaker
The toughened bow means the ship can smash through ice up to one metre thick.

On-board stores
It can remain at sea for up to two months unsupplied.

HOW FIGHTER JETS REFUEL MID-AIR

RAF VOYAGER IS A FLYING TANKER, ON A MISSION TO KEEP FIGHTER JETS ALOFT FOR AS LONG AS POSSIBLE

Words by **Scott Dutfield**

Staring out of the window of an Airbus A330 aircraft, the sight of a fighter jet flying alongside is something not many people get to see. However, for members of RAF 10 and 101 Squadrons, it's a daily occurrence. A seemingly standard-looking airliner that's larger than most passenger jets, the RAF Voyager has been commissioned to act as the air force's flying ferry and fuel supply. During this year's Joint Warrior exercise, **How It Works** was given the opportunity to hop aboard the valiant Voyager and see first-hand the important role this aircraft plays in keeping pilots in the sky.

More than 10,000 military personnel from the UK and NATO took part in the large-scale training exercise, which spanned land, sky and sea. During the two-week event 59 aircraft took to the skies in participation, including the RAF Voyager (A330 MRTT) to offer fighter jets air-to-air refuelling.

Heading towards the west coast of Scotland, waves of Typhoon and F-35 Lightning II jets approached either side of the Voyager before disappearing momentarily to get into position for refuelling. Making a connection to a deployed fuel hose, the overall process mimics that of a mechanical hummingbird, gently approaching the fuel basket and inserting its slender steel beak to draw its fill of jet fuel – all while travelling at 885 kilometres per hour. Refuelling takes around five minutes before the next jet is ready to get in position.

Although part of a legacy of refuelling aircraft, the Voyager is the UK's first to sport three locations on its body where it can

Aircraft across the UK's military fleet can sidle up to these fuel stations in the sky for a power top-up

Fuel hoses and baskets are deployed from pods from the aircraft's wings

The RAF Voyager is flown on a daily basis for the refuelling of passenger-carrying missions

Flying legacy

Air-to-air refuelling is not only a modern-day marvel for military missions. This flying feat was first achieved in 1923, when a DH-4B carrying Lieutenants Virgil Hine and Frank W. Seifert passed fuel to a DH-4B flying beneath them carrying Lieutenants Lowell H. Smith and John P. Richter. The process of getting the fuel from one plane to another was very much a game of throw and catch. The refuelling hose was manually tossed from the tanker plane and caught by the pilot of the receiver plane. Only capable of holding around 420 litres of fuel, during the manual refuelling 284 litres of passed between the two aircraft.

Since those pioneering pilots made the first fuel transference, in-flight fuelling has played a vital role in cementing aerial success in several conflicts. The introduction of the Lockheed TriStar in the 1970s, a three-engined air tanker capable of soldier transport and air-to-air refuelling, played a key role in conflicts such as the First Gulf War, Falklands War and in Afghanistan. Before retiring from the RAF in 2014, the TriStar paved the way for its replacement – the Voyager.

The first successful aerial refuelling took place on 27 June 1923, about 150 metres above Rockwell Field

dispense fuel. Previously, air-to-air refuelling could only be achieved at the rear of an aircraft. However, the Voyager is equipped with additional refuelling pods on both of its wings.

This improved design is the result of some clever cut-and-paste engineering. "This aircraft was built from scratch, they used an Airbus A340 wing and bolted it to an Airbus A330", said Martin Blythe, RAF mission systems operative. "An A340 is a four-engined airliner, but the Voyager is two-engined. Where the other engines would have been is where we have put our pods".

These pods are where the fuel hoses and baskets are held during flight and deployed for refuelling. Air-to-air refuelling occurs at around 6,000 metres, much lower than the altitude at which a commercial flight travels. Aboard the Voyager is a single fuel tank, not only to dispense to jets in need of a top-up but also for the Voyager itself. Burning at a rate of around six tons an hour, it's a balancing act between the amount of fuel the Voyager can supply to other aircraft and what it needs to retain for itself. However, with the ability to hold over 100 tons of fuel, this flying fuel station can stay in the sky for hours.

"This plane is a game-changer in how much fuel it can carry, Blythe says. "Legacy aircraft such as the TriStar could go equally as far, but that aircraft only had one hose and this one has three hoses, one on each wing and one on the tail, so the benefit to us is we can simultaneously refuel aircraft at the same time".

A mission support officer monitors the refuelling process via screens in the cockpit

Air-to-air refuelling

How do fighter jets pump petrol from flying fuelling stations?

1 Deploying the hose The fuel hose and basket, also known as a drogue, is released from the wing pod and can extend up to roughly 27 metres to meet the receiving fighter jet.

2 Careful approach Having extended its fuel probe, the fighter jet gently accelerates and inserts the probe into the inflated basket to collect fuel.

3 Filling station Once in the correct position, the fuel valve will open and jet fuel will flow down into the hose across the coupling, and through the probe to the fighter jet's fuel tank.

4 Disconnect With a full tank of fuel, the fighter jet reduces its speed and pulls away from the hose, closing the fuel valve to prevent fuel leakage as it disconnects.


Voyager replaced TriStar in 2014, and has superior refuelling capabities

The RAF Voyager

Wingspan: **60.3 metres**
Maximum speed: **Around Mach 0.86 (approx. 1,060 kilometres per hour)**
Maximum altitude: **Approx. 12,500 metres**
Maximum fuel load: **111,000 kilograms**
Maximum passenger load: **291**
Length: **58.82 metres**
Height: **17.39 metres**
Power: **Two 316 kilonewton Rolls-Royce Trent 772B turbofans**

"This plane is a game-changer in how much fuel it can carry"

Q&A

RAF mission systems operative Martin Blythe

How is the fuel hose deployed and retracted?
The hose goes out on a hose drum that is controlled by an electric motor. At the end of the hose is a big basket that inflates – this is what the receiver makes contact with. The basket also acts as a drag parachute, so it pulls the hose out, and the electric motor is always trying to pull it back in. When the hose reaches its maximum extent, it moves in and out about three or four times. That's the taut motor establishing how taut the hose needs to be to maintain a balanced position. When we've finished refuelling we increase the motor power so it overcomes the amount of drag, and we pull it back in.

How is fuel released to fighter jets?
We first force fuel into the hose, which increases its weight. That also stabilises the hose while it's flying and makes it more stable for the receiver. Once that is complete the logic box, a box of electronics in the pod, says, 'Right I'm ready now for refuelling', and we turn on the traffic light system. A red light informs the receiver [when contact is] not allowed, for example. We then verbally give them clearance on the radio: "clear contact". We turn the red light off, so they've had a visual cue and oral cue, just in case one fails. The pilot puts on a bit of extra power, and with both aircraft travelling at 550mph [885kph] they only need one to two extra miles an hour to reach the basket.

How does the pilot access the fuel?
There's this 'dance in the air'... at ridiculous speeds but actually the closing speed is minute. The pilot makes contact with the basket with their probe and starts to push into the hose. There are some white bar markings on the hose, and when they see the first set of triple bars it opens the fuel valve at this sweet spot. The fuel will start coming down at around one ton a minute. If the pilot keeps pushing and they get too close, which they don't want to do because it's dangerous for us, it turns the fuel supply off. They will drop back... and the fuel valve opens again. It's all about keeping the hose between those hose markings.


Fighter jets such as the F-35 Lightning II take around five minutes to refuel from the Voyager

WHY IS THE UNIVERSE EXPAND

There's a secret, invisible force that lies behind the constant expansion of the cosmos...

Words by Lee Cavendish

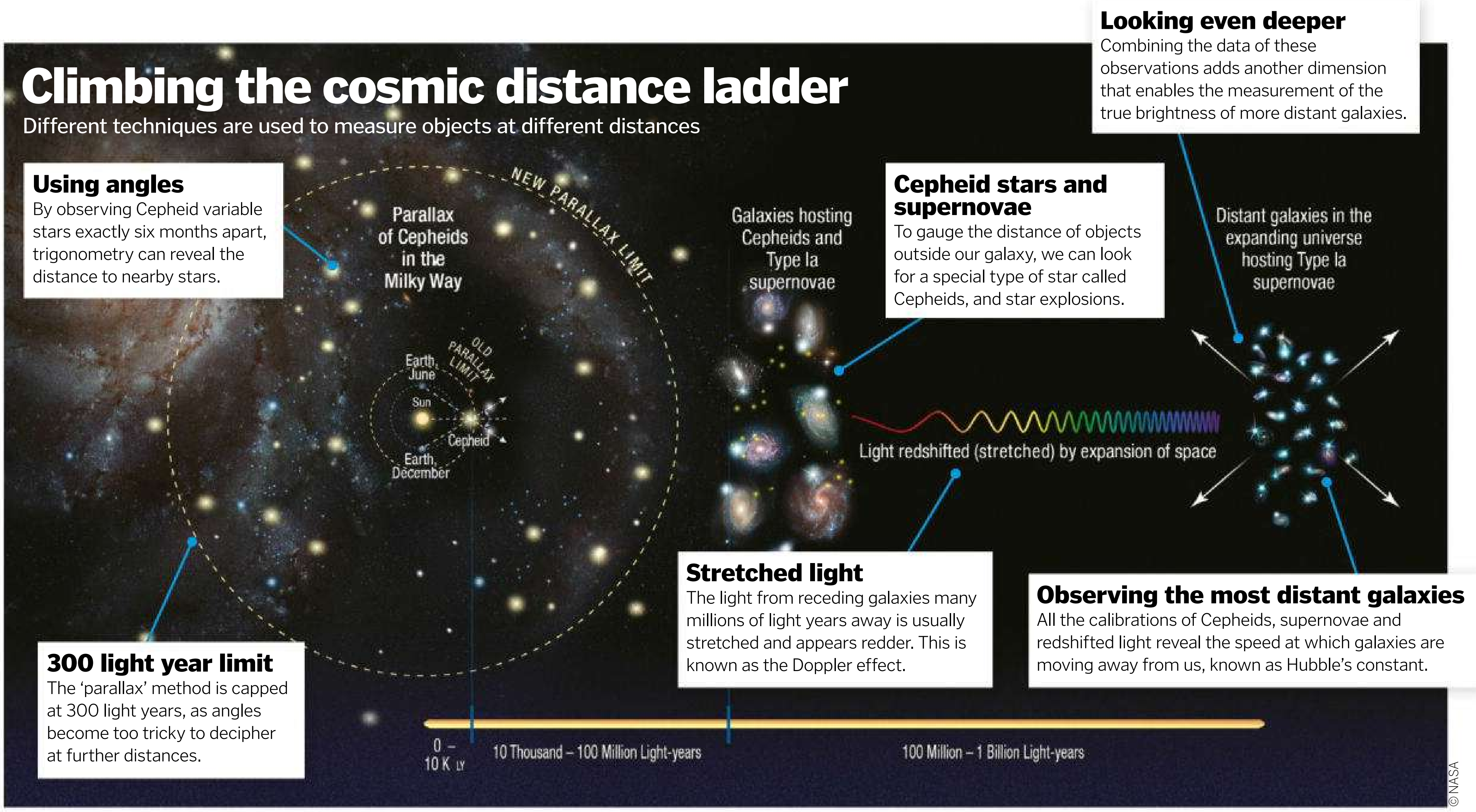
Imagine that the universe is a balloon with dots drawn all over it. A deflated balloon is much like the state of the universe 13.8 billion years ago – all crammed into a single, dense point. Then came the Big Bang: an influx of energy occurred in an instant that blew out the universe, much like blowing up a balloon. With each blow of the balloon, you would notice the dots getting further and further away from each other, yet there isn't any new material in between them as they are drawn on the same balloon. The balloon, much like our universe, is expanding thanks to the blowing of air, or in the case of the universe, dark energy.

Dark energy is just part of the cosmic expansion theory, driving the expansion of the universe, but it is an area of astronomy that has been heavily studied in the quest for definitive answers for almost a century. There have been new revelations thanks to a developed understanding on things such as Einstein's General Theory of Relativity, Hubble's constant and the cosmic microwave background (CMB). These are now the best observations and theories that explain the expansion theory.

After the Big Bang, the cosmos was essentially a ball of hot, dense particles that were unable to latch together to form even the simplest hydrogen molecule because the cosmos was just too energetic. As it expanded, the universe began to cool, particles were colliding constantly and electrons and protons were able to bond to form hydrogen. This is known as the epoch of recombination. Soon after this event was the release of electromagnetic radiation that can be seen today in the form of the CMB, and was only discovered in the 1960s.

In the 1920s American astronomer Edwin Hubble revealed that distant galaxies are in fact moving away from us. So over the course of almost 13.8 billion years, there has been the creation of atoms, molecules, stars, the solar systems and galaxies, and the only thing that has stayed consistent is that the universe has carried on expanding due to the strength of dark energy, which makes up approximately 74 per cent of the universe.

Galaxies are the most luminous objects so are easier to detect in the distant cosmos



DING?

Over the last decade astronomical techniques have been refined in order to correctly derive the rate of expansion. By watching distant variable stars (stars that vary in brightness, called 'Cepheids') and supernovae, astronomers have been able to measure the distance of galaxies and track their apparent motion relative to us. Using this technique, Nobel Prize of Physics laureate Adam Riess discovered in 2016 that the universe is expanding five to nine per cent faster than originally believed. But this could all change if a new theory comes to the floor.

Supernovae, like the one that created the Crab Nebula (M1) remnant, are used to measure cosmic distances

The man behind the theory

The early 20th century saw the publication of Albert Einstein's General Theory of Relativity, and while everyone was trying to understand it and its role in the universe, Edwin Powell Hubble was understanding the mystery behind the expansion. Hubble was an American astronomer who dedicated his life's work to understanding the movement of distant galaxies.

In 1929 Edwin Hubble made a shocking announcement to the scientific community. By measuring the redshift of a number of distant galaxies' distances and their apparent motions relative to the Milky Way, he showed that distant galaxies are moving away from us faster than nearer ones. Hubble realised that a galaxy's receding speed correlates to its distance, and the speed at which they're moving away is now known as 'Hubble's constant'. This innovative discovery challenged Einstein's theory, brought in the age of observable cosmology and introduced the world to the idea of an expanding universe.

Edwin Hubble conducted his research at the Carnegie Observatories in Pasadena, California, US

Ultimate fate of the universe

Cosmologists say that the universe could end in one of four ways

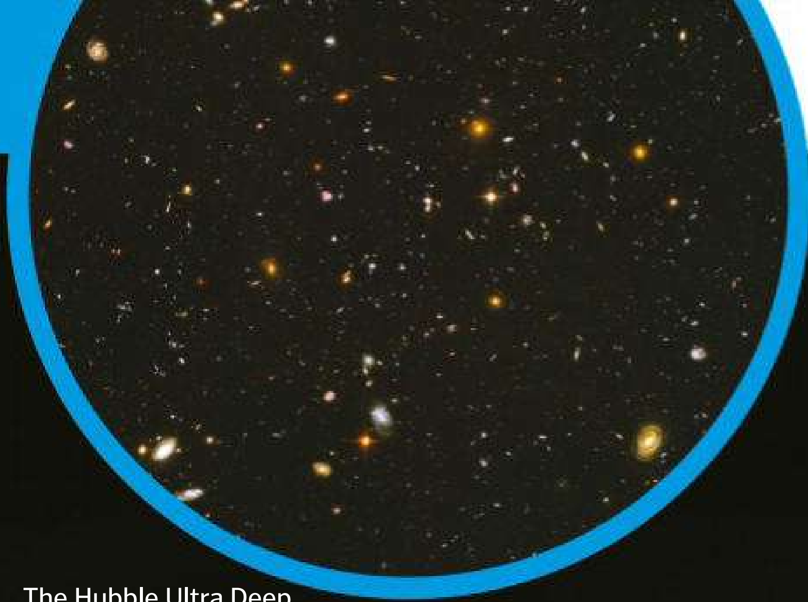
Big Freeze
Much like how the universe expanded and cooled after the Big Bang, which led to the formation of the first hydrogen molecules, the universe could carry on expanding until it reaches absolute zero. Absolute zero is theoretically the lowest temperature possible, meaning the universe would have no energy to move.

Big Rip
The Big Rip is dependent on the rate of expansion increasing dramatically with time. What if there is more dark energy as time goes on? The rate of expansion would increase and increase until all forms of matter in the universe, starting with galaxies, will be ripped apart, to the point where molecules won't be able to stick together.

Big Crunch
Going back to the balloon metaphor, after you stop blowing a balloon and let it go, it will contract again. This is the idea behind the Big Crunch, as dark energy won't have the power to continue the expansion and the universe will begin to fall back into itself.

False vacuum
People often talk about the 'vacuum of space', which basically means an area with as little energy as possible. However, a false vacuum is the idea that it's possible to have even lower energy – true vacuum state. If the universe was to drop into this lower energy, the universe could disintegrate. This is also known as vacuum decay.

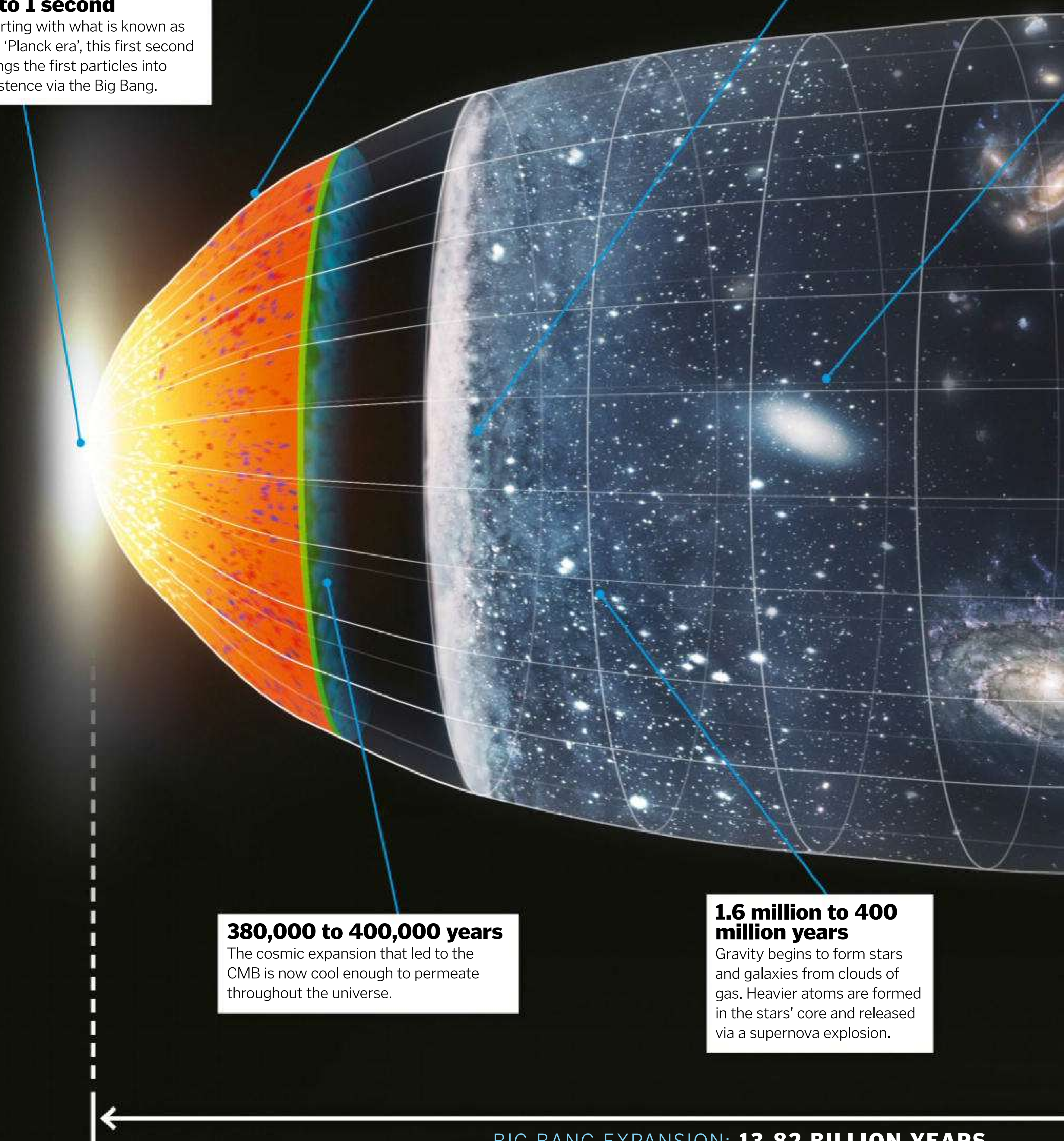
"The universe will begin to fall back into itself"



The Hubble Ultra Deep Field image reveals the most distant observed galaxies, shown in red due to redshifting

An expanding universe

The universe has constantly been getting bigger since the Big Bang



0 to 1 second
Starting with what is known as the 'Planck era', this first second brings the first particles into existence via the Big Bang.

1 second to 380,000 years
After 380,000 years the first atoms – mainly hydrogen and helium – are formed. Hydrogen is the most abundant element in the universe.

150 million to 1 billion years
The 'Reionisation era', which sees ancient luminous sources (thought to be stars, dwarf galaxies or quasars) ionising interstellar gas.

380,000 to 400,000 years
The cosmic expansion that led to the CMB is now cool enough to permeate throughout the universe.

1.6 million to 400 million years
Gravity begins to form stars and galaxies from clouds of gas. Heavier atoms are formed in the stars' core and released via a supernova explosion.

BIG BANG EXPANSION: **13.82 BILLION YEARS**

Watching stars explode

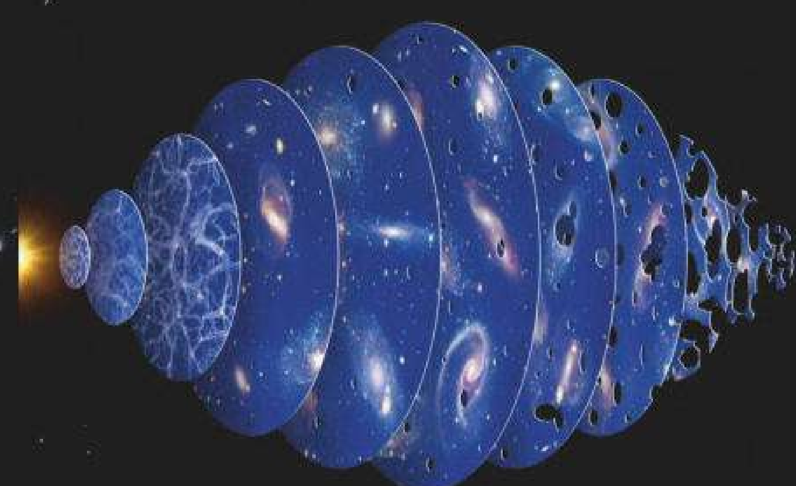
In 2011 three astronomers – Saul Perlmutter, Brian Schmidt and Adam Riess – won the Nobel Prize in Physics for their work on the discovery of the accelerating expansion of the universe by observing over 50 distant supernovae.

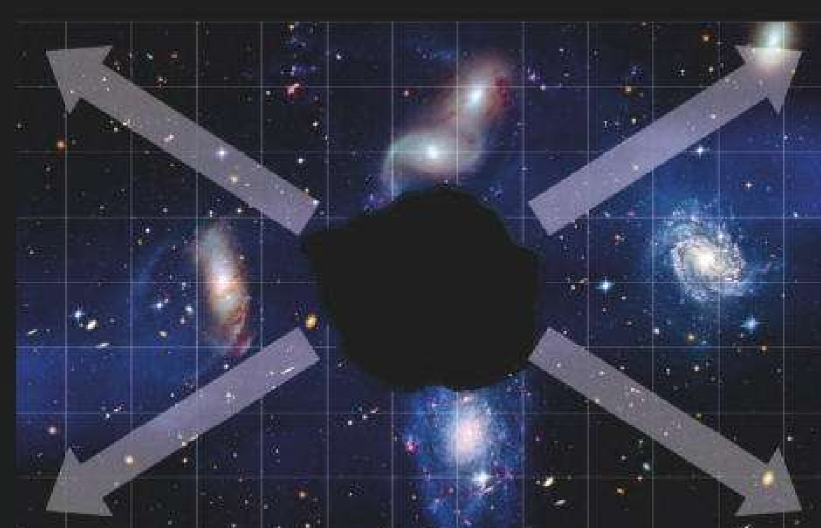
This discovery was made using data collected by the NASA/ESA Hubble Space Telescope (HST), the famous telescope named after the influential astronomer.

Data collected by the HST showed that in its early stages the universe was expanding slower than expected, meaning that as the universe expanded, dark energy began to dominate.

© NASA/ESA/L. Frattare (STScI)

The astronomers selected a specific type of supernovae, Type Ia, from distant galaxies





The Big Rip is one of the endgame scenarios for continuous expansion

Meet the Mars Starship

How this prototype space vehicle could one day take humans to the Red Planet

The US company SpaceX has made no secret of its ultimate goal to send humans to Mars. They hope to do this with a large new spacecraft called Starship, capable of carrying 100 people or so per flight, launching on top of a huge rocket called the Super Heavy, in total measuring over 100 metres tall. But to prove that this idea works, SpaceX has been busy testing a prototype vehicle called Starhopper.

Starhopper is a scaled-down version of the reusable Starship and Super Heavy combination – about one-third of the size. It's equipped with three Raptor engines, methane-fuelled rocket engines that will be used for launches to Mars. And in early April 2019 Starhopper performed a very small test 'hop' at a test site in Texas, where it fired up and lifted a few feet off the ground while remaining tethered to Earth.

There had been some problems prior to the hop, notably strong winds that caused the nose cone on top of the rocket to become damaged and unusable. But the hop itself was a success and proved that the design for the vehicle would indeed work. SpaceX is expected to soon conduct further tests of Starhopper, where it will not be tethered to the ground so it can fly much higher.

SpaceX hopes to begin flights of Starship in the 2020s, and it is already at work on the full-scale final vehicle. One of its first flights is set to be a trip around the Moon with space tourists on board in 2023, and after that, who knows? Perhaps Elon Musk's company really will be able to send people to Mars.

© SpaceX

A 2015 test firing of the raptor rocket engine designed for SpaceX launch vehicles

Can it be done?

Many questions have been raised about whether SpaceX can actually pull off this idea. At up to £400,000 a ticket, it won't be cheap for passengers to travel to Mars – but Musk has likened it to buying a house and hopes people will be willing to live on another planet rather than on Earth. However, SpaceX's plans will require billions and billions of pounds to be successful. What's more, no one has ever attempted to launch so many people on a single launch. Ultimately, will the desire simply be there to attempt to colonise other worlds?

© SpaceX

SpaceX has its eye on destinations like Saturn, but significant investment will be required

SpaceX vehicles

Starship has gone through multiple variants and is significantly bigger than the Falcon 9

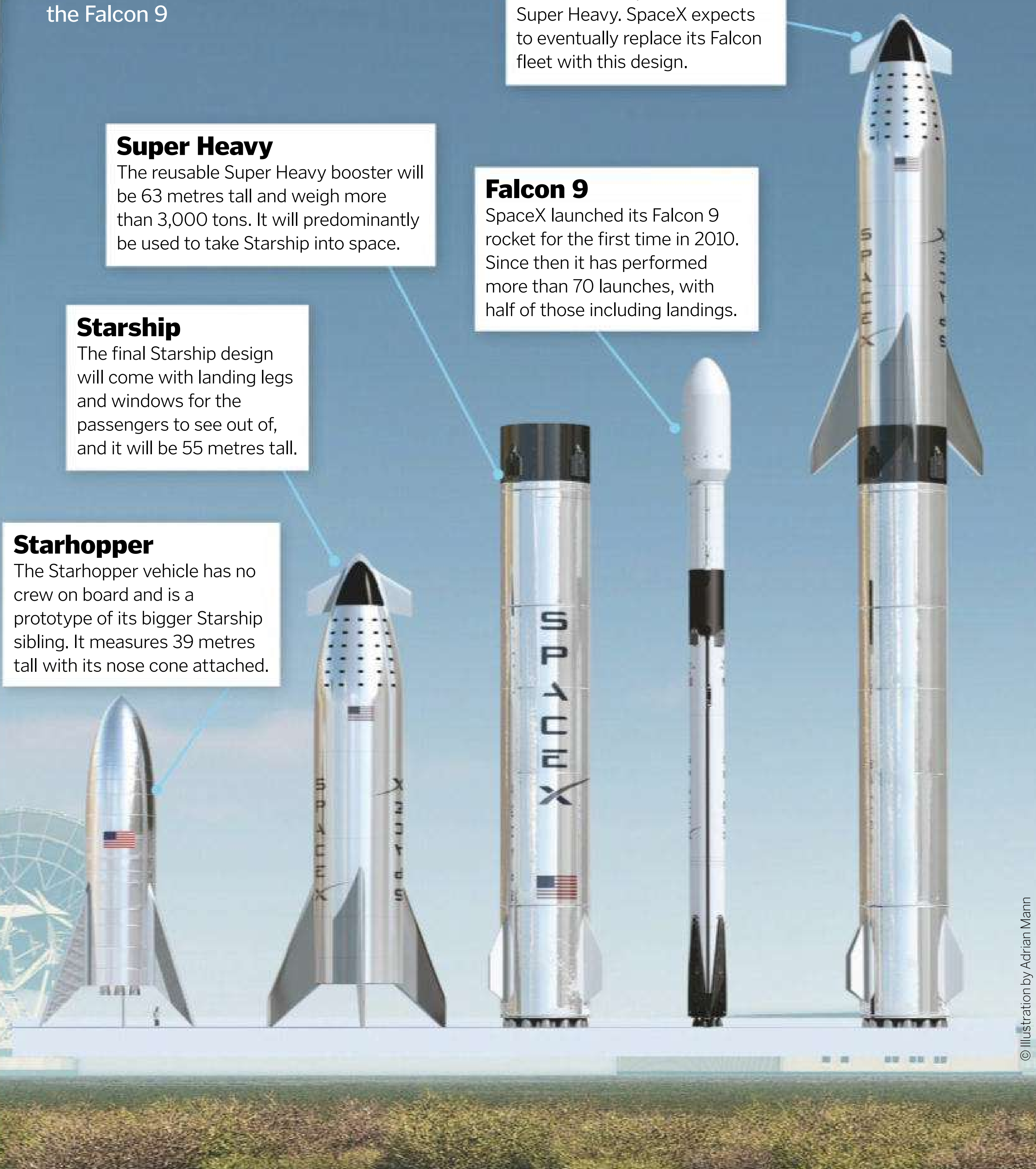
BFR
Originally called the Big Falcon Rocket (BFR), the final design will see Starship attached to the Super Heavy. SpaceX expects to eventually replace its Falcon fleet with this design.

Super Heavy
The reusable Super Heavy booster will be 63 metres tall and weigh more than 3,000 tons. It will predominantly be used to take Starship into space.

Falcon 9
SpaceX launched its Falcon 9 rocket for the first time in 2010. Since then it has performed more than 70 launches, with half of those including landings.

Starship
The final Starship design will come with landing legs and windows for the passengers to see out of, and it will be 55 metres tall.

Starhopper
The Starhopper vehicle has no crew on board and is a prototype of its bigger Starship sibling. It measures 39 metres tall with its nose cone attached.



© Illustration by Adrian Mann

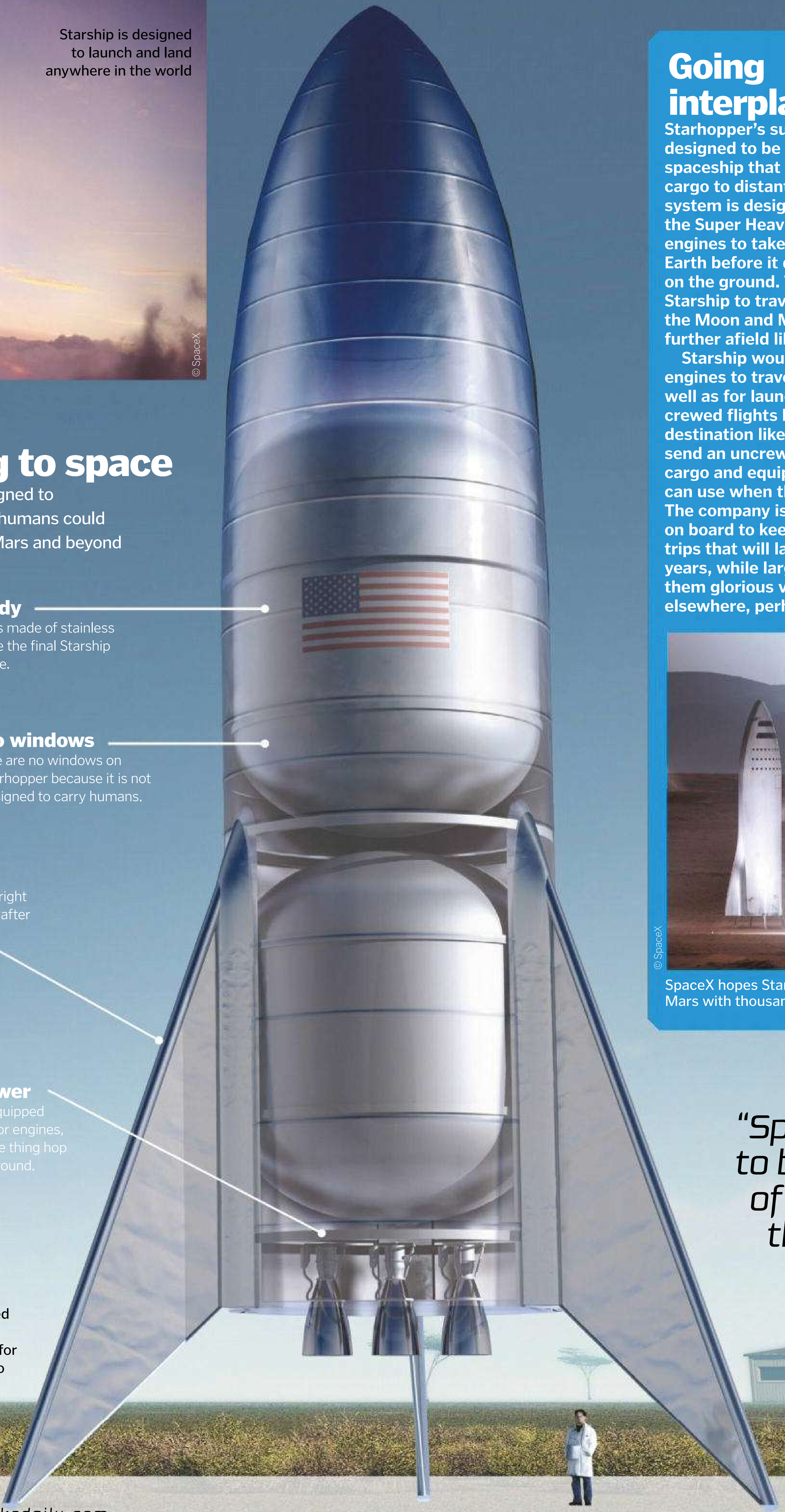
DID YOU KNOW? *SpaceX launched its first rocket, the Falcon 1, in 2006. It failed three times before successfully launching*

Starship is designed to launch and land anywhere in the world

© SpaceX

Hopping to space

Starhopper is designed to demonstrate how humans could one day travel to Mars and beyond



Steel body
Starhopper is made of stainless steel, just like the final Starship vehicle will be.

No windows
The are no windows on Starhopper because it is not designed to carry humans.

Tripod
Three legs enable Starhopper to stand upright and touch down gently after launching into the air.

Raptor power
Starhopper is equipped with three Raptor engines, letting the whole thing hop briefly off the ground.

Starhopper is designed to test some of the technologies needed for eventual missions into the Solar System

Going interplanetary

Starhopper's successor, Starship, is designed to be an interplanetary spaceship that can take humans and cargo to distant destinations. The entire system is designed to be reusable, with the Super Heavy booster using its 31 engines to take Starship into space from Earth before it detaches and lands back on the ground. This would then enable Starship to travel to locations including the Moon and Mars, and potentially even further afield like Jupiter's moon Europa.

Starship would use seven Raptor engines to traverse the Solar System, as well as for launch and landing. Before crewed flights begin to head to a destination like Mars, SpaceX plans to send an uncrewed vehicle laden with cargo and equipment that the passengers can use when they arrive on a later flight. The company is planning entertainment on board to keep the passengers busy on trips that will last multiple months or years, while large windows will also afford them glorious views as they travel elsewhere, perhaps to live permanently.

© SpaceX

SpaceX hopes Starship can be used to colonise Mars with thousands of people

"SpaceX hopes to begin flights of Starship in the 2020s"

INTERVIEW

Professor Brian Cox

The world-famous physicist tells us about his new BBC series, how the Solar System was formed and the next big space mission

© Getty

Astronomer Brian Cox needs little introduction: while studying for his physics masters at the University of Manchester in the mid-90s, he enjoyed some success as a keyboard player with the pop band D:Ream, before he quit the band to pursue his research at various particle accelerator facilities, including CERN.

Later, his enormously popular 2010 series *Wonders of the Solar System* and its two follow-ups, *Wonders of the Universe* and *Wonders of Life*, cemented his position as the face of UK science broadcasting.

© BBC

A few billion years from now we can expect the Sun to expand and swallow up the Earth

What's new about *The Planets?*

I think what's been remarkable over the last decade or so is the amount of detail that we've been able to put into the story of the Solar System, mainly proven by new missions. If you go back to 2009, when we were making *Wonders of the Solar System*, the Cassini probe had only just arrived at Saturn.

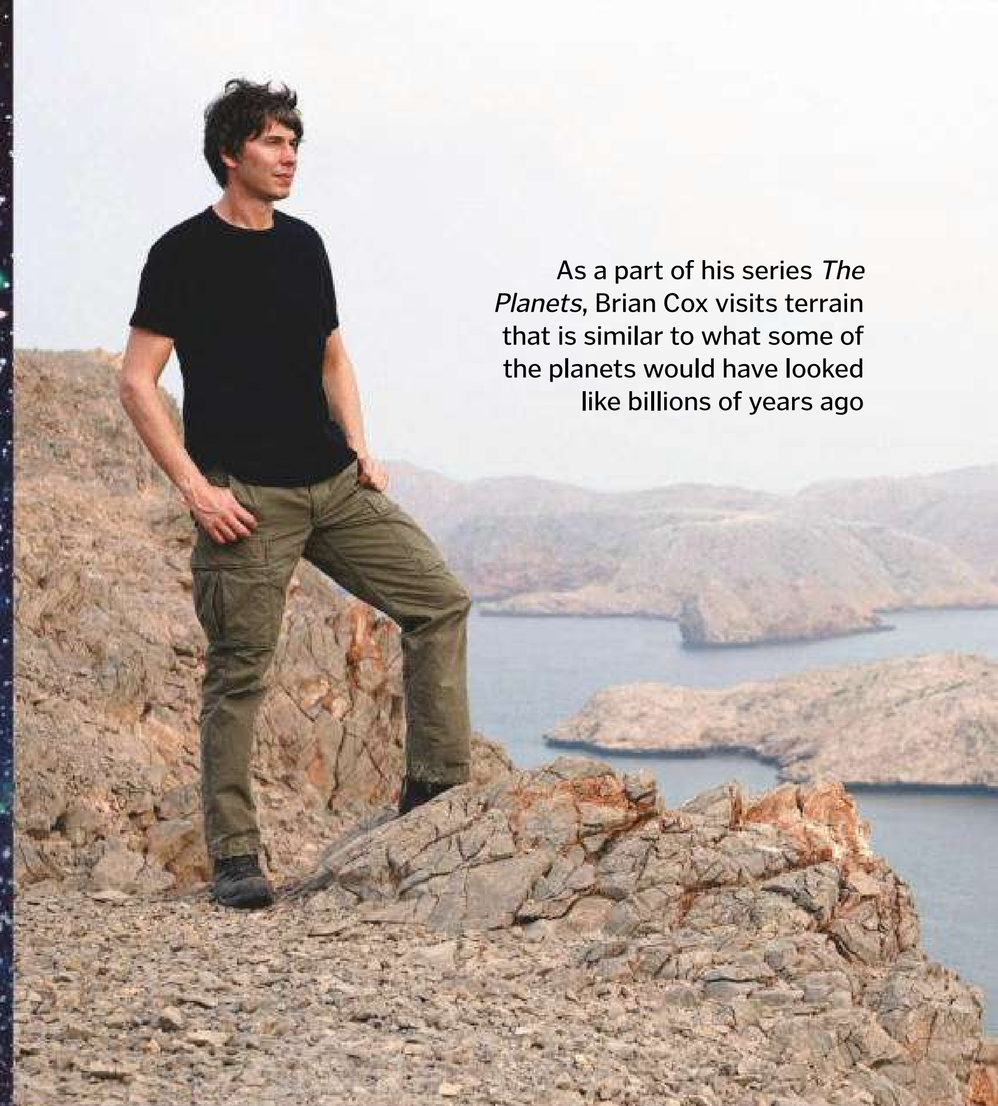
Secondly, the Grand Tack model [a theory in which Jupiter migrated inwards after its formation and then much further outwards to its current position] seems fantastical and contrived. But that's only a recent development based on both observations from space probes and an increased sophistication in computer modelling of the Solar System.

Thirdly, the increasing number of observations of other solar systems. It's critically important for our understanding of the Solar System today that we've now seen well over 3,000 planets around distant stars, and what we've seen is that the geography and the layout of other solar systems in general are not like ours.

So it's a combination of a lot of data from a lot of spacecraft. What's quite exciting from a scientific

> "At some point we will be the Martians. That's clear to me, because we can't stay here forever"

Earth during the time of the early Solar System would have been a geologically violent planet



As a part of his series *The Planets*, Brian Cox visits terrain that is similar to what some of the planets would have looked like billions of years ago

perspective is that [NASA's spacecraft] Juno, which is providing magnificent, very strange images of Jupiter and its poles with its different colours and swirling clouds – that spacecraft has not really had an impact yet on our pitch of the development of Jupiter in the Solar System, as the data is just coming back.

Was there anything you learned from filming this latest series?

Absolutely: the idea that Mercury almost certainly formed much further away from the Sun. This is a very new idea, based on a spacecraft that went there and observed the chemical composition of the surface and returned these tremendous surprises, particularly about the elements sulphur and phosphorus on the surface, which were not present close to the Sun when the planets were forming. They only existed in large quantities further out. Observations like that, when you begin to piece them together with the modelling, tells you that our Solar System is significantly more dynamic in terms of the geometry of the Solar System today.

I think we tend to think of our Solar System as a fossilised remnant of the initial dust cloud that collapsed. So the initial structure around the Sun 4.6 billion years ago or so is echoed in the distribution of planets today around the Sun. What we've learnt recently, and what was surprising to me, is that it is not the case. The Solar System was very dynamic, and planets were moving around all over the place in the early years.

Where would you like human space probes to visit next?

The next big mission from NASA is the Europa Clipper. It's a Jupiter orbiter, but it's focused on [its moon] Europa. I think the big questions now are astrobiology, and what we deal with in a couple of the other programmes in the series is; is there life – particularly on Mars and on some of the icy moons? That's what the Europa Clipper mission is designed to answer, and it's also designed to scope out landing sites on Europa and try and understand whether it may be possible to get something into the ocean below the icy surface.

I expect after the Europa Clipper, the one after that would probably be a Titan mission. Titan's a planetary-sized moon with a very thick atmosphere, it has a liquid water ocean below the surface, a long way down, and it has the most complex organic chemistry of any other body other than Earth in the Solar System.

Brian Cox's latest series, 'The Planets', is currently available to watch on BBC2, Tuesdays at 9pm throughout June, and also on catchup via BBC iPlayer.

There is a plan to put what is essentially a helicopter onto Titan in the form of a drone. That's great, because the gravity of Titan is a ninth of Earth's gravity, and the atmosphere is denser, so you can fly anything around it.

I think astrobiology is going to be the focus of the next two big NASA missions. Beyond that we would like to see orbiters around Neptune. There's a lot of pressure to put an orbiter around Neptune but it's very, very difficult to do.

What do we have to consider in possibly colonising Mars?

I did an interview the other week and I wanted to be sort of shocking and challenging so I said, "If there's no life on Mars, I don't care what we do to it," which is not quite true, because what about those beautiful vistas and things. So that's not the quote, but it will be now. That was sufficiently naive of me.

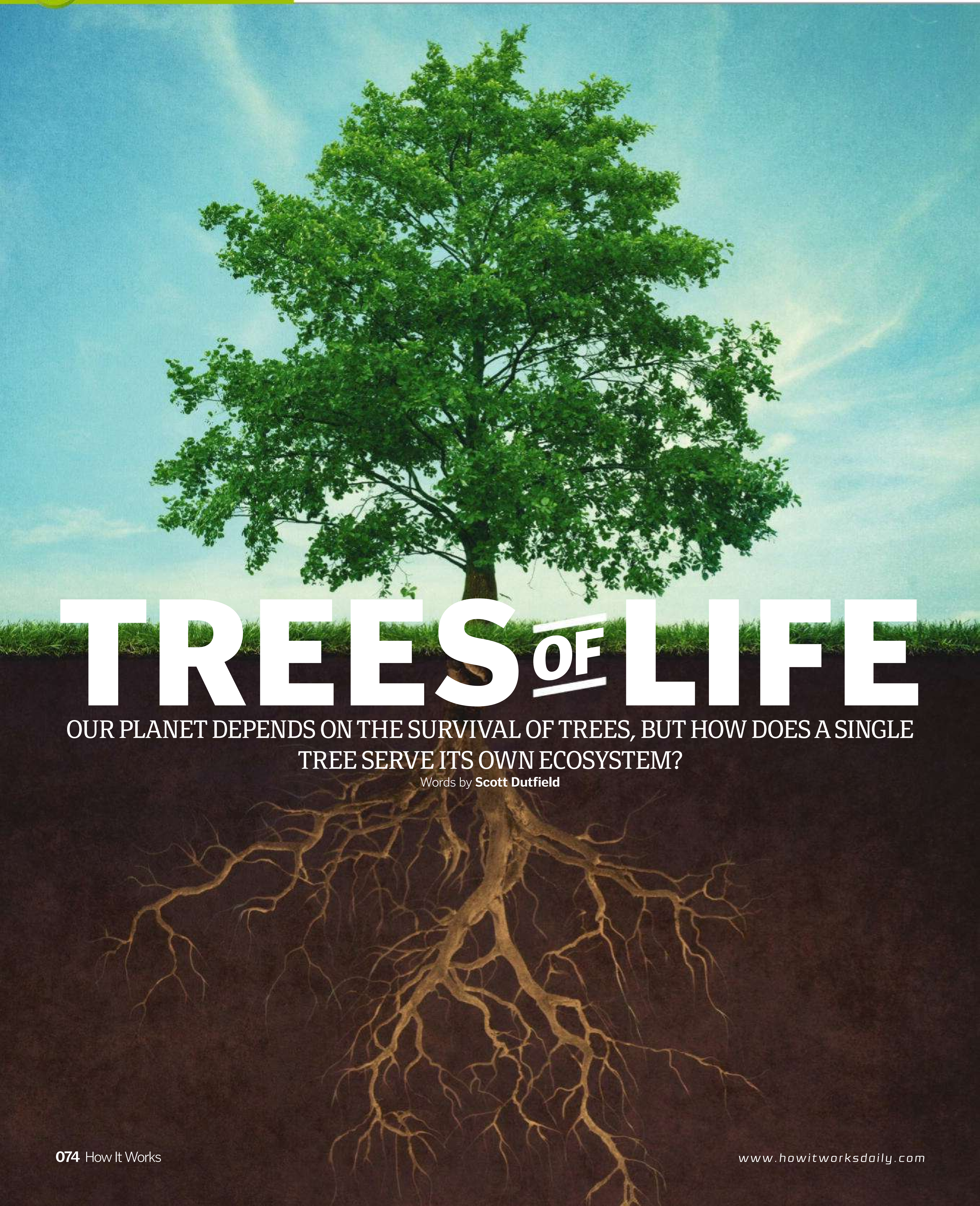
So in a sense, if there's no life on Mars then I don't think the ethical consideration arises. But if there are microbes, and we think about this very carefully in terms of the places we land on Mars and the way we treat the spacecraft out there, we do not want to contaminate it with Earth microbes. There's a scientific reason for that, which is that if there is life there, we'd like to see if there was a second genesis or whether there was a single genesis on Earth or Mars, because we know organic material can be transferred between planets. So it ruins the science.

I think we have to be very careful from a scientific perspective about damaging potential ecosystems on Mars, and we are extremely careful; it's called 'planetary protection', we take it very seriously. But at the same time, I don't think that can stop us from going to Mars. It is actually the only place we can go beyond Earth in any plausible scenario.

I say in the Mars episode, I actually make this case, I say that there may not have been Martians and we need to find out, but there will be Martians if we're to have a future. At some point, we will be the Martians. That's clear to me, because we can't stay here forever.

If you could go back to any point in time and space, when and where would you go?

If I could go back in space and time, I'd like to go and see Mars when it had oceans. One of the things that worked very well in the graphics was recreating Mars and what we think it would have looked 3.8 billion years ago, before it began to lose its atmosphere.



TREES OF LIFE

OUR PLANET DEPENDS ON THE SURVIVAL OF TREES, BUT HOW DOES A SINGLE TREE SERVE ITS OWN ECOSYSTEM?

Words by **Scott Dutfield**

Reaching across millions of kilometres, the world's forests are the heart and soul of our global ecosystem. Trees are the yin to mankind's yang: they absorb the carbon dioxide we exhale, and in return they release the precious oxygen our bodies depend on, creating an atmospheric balance. During a tree's lifetime, it will absorb a ton of carbon dioxide, producing around 118 kilograms of oxygen a year in return.

While collectively acting as Earth's air purifier, each individual tree exists in its own micro-ecosystem. From seedling to skyscraper, trees are often at the centre of these ecosystems, facing the demands for food, shelter and protection from other species. For example, a single tree growing in a tropical rainforest can support around 2,000 different species from across the animal kingdom as well as plant and fungi species.

Fundamentally the role of trees in a micro-ecosystem is to transfer energy in a biological chain, from sunlight to seed production and beyond. Through photosynthesis, trees utilise the energy of the Sun's light to transform absorbed carbon dioxide and water into glucose and oxygen. Stored as chemical energy in glucose, a tree will use this to grow its leafy body and produce its fruits. This chemical energy is then transferred once more to the animals and insects via a free buffet of fruits, leaves, pollen and nuts. In turn, these creatures will use this obtained energy to survive, and even benefit the tree by dispersing its seeds.

"Each individual tree exists in its own micro-ecosystem"

This gifting of energy is not the only way in which trees serve members of a biological community. Non-living 'abiotic' parts of an ecosystem are also kept in check by the presence of trees. Both a tree and the soil it is rooted in mutually benefit from the other's existence. Soil acts as a tree's resource bank of water, minerals and nutrients to be withdrawn by its roots, while fallen leaves and branches restore nutrients to the ground as they decompose. The complex network of roots not only anchor the tree but compact the soil to save it from erosion by rainfall.

The biological and chemical interactions surrounding a single tree are intertwined and affected by the rest of the forest ecosystem and our global ecosystem. A disturbance to smaller ecosystems can have a domino effect on larger ones. For example, during the process of deforestation, each biological community supported by a single tree is also removed. In turn, this can have a negative effect on the diversity of species and the fertility of the land.


© Getty

Gumivores such as the pygmy marmoset feast on the oozing sap of a tree


© Alamy

Gall wasp larvae release a chemical to create their own homes on a tree

The acorn and the wasp

Creating a habitat for animals and insects is a significant role of an oak tree, even when it's tricked into doing so. Found across the leaves, bark and even acorns of many oak trees are small plant pimples called galls. Although they appear as part of the tree's natural knobbly development, galls are in fact the result of a particular group of wasps forcing the tree to build them their very own safe haven. Upon laying its eggs in the tree, the gall wasp larvae secrete saliva that affects the tree's growth process. In response, the oak tree produces these strange growths, which encase the larvae within. Once engulfed in their temporary wooden shield, the wasp larvae pupate and later emerge as adult wasps.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Many mammal species, such as the pine marten, make use of tree hollows to form their own home


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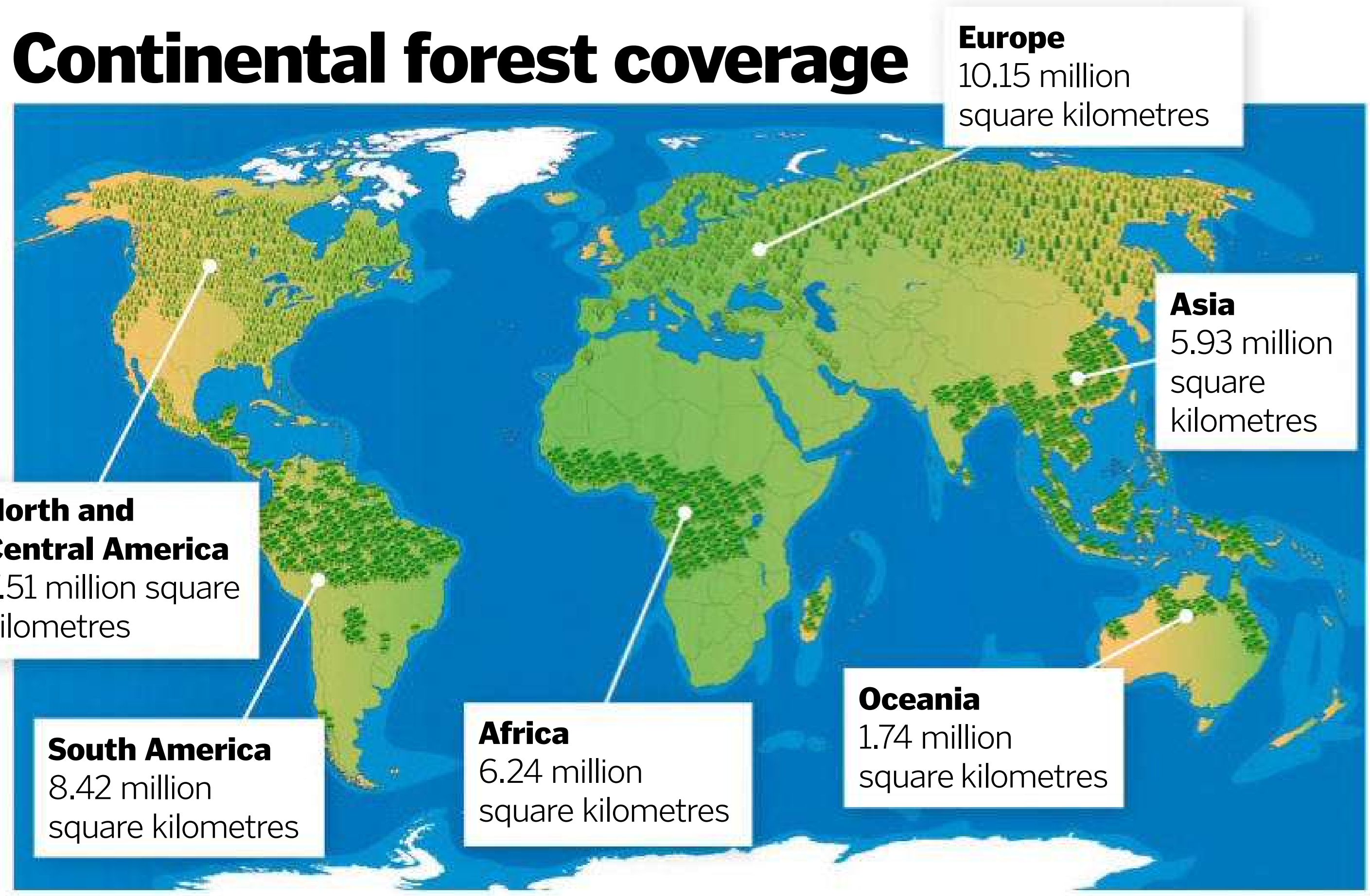
Lichen can act as a biological indicator of the health of an ecosystem because it absorbs pollution

Continental forest coverage



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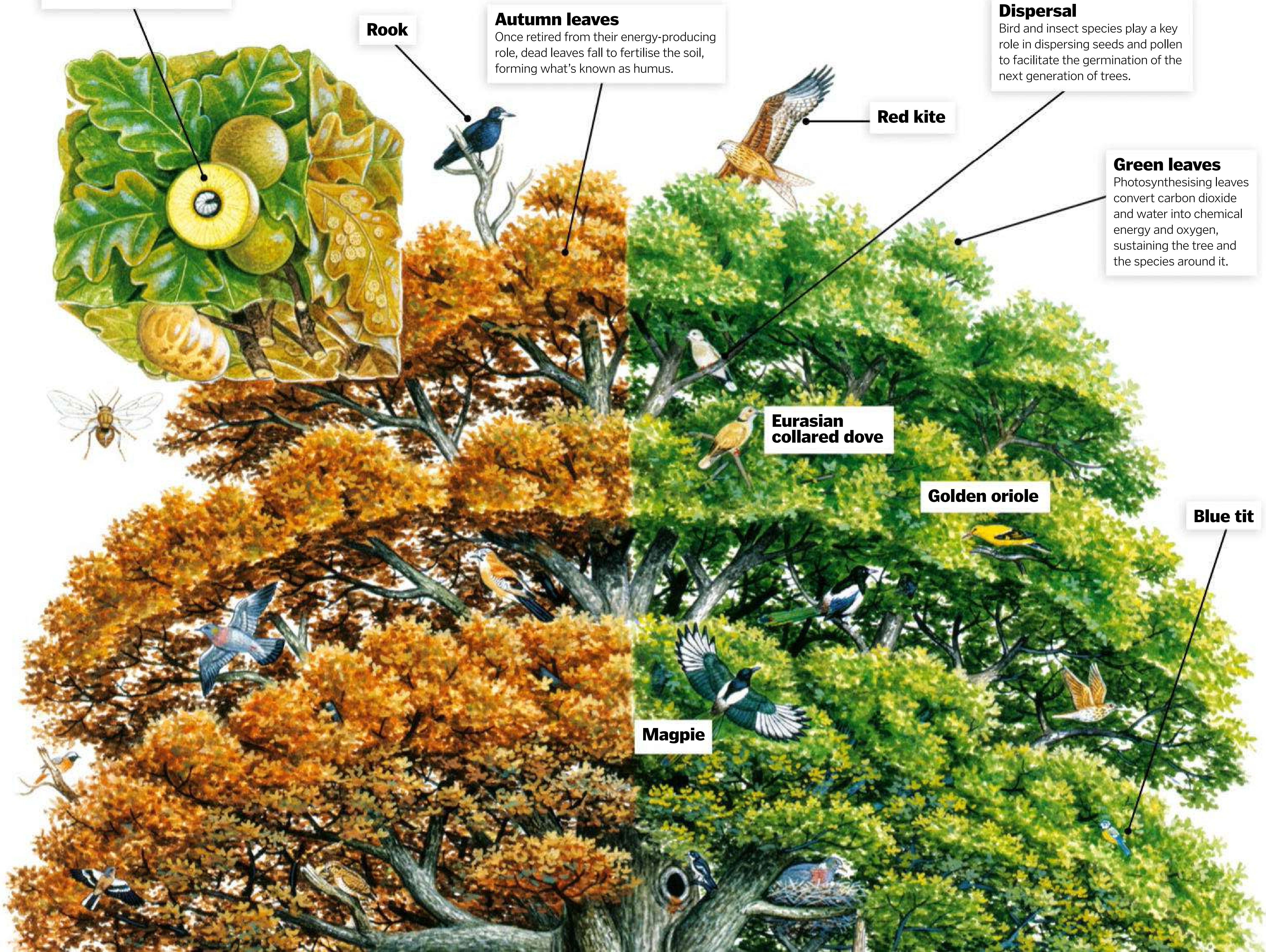
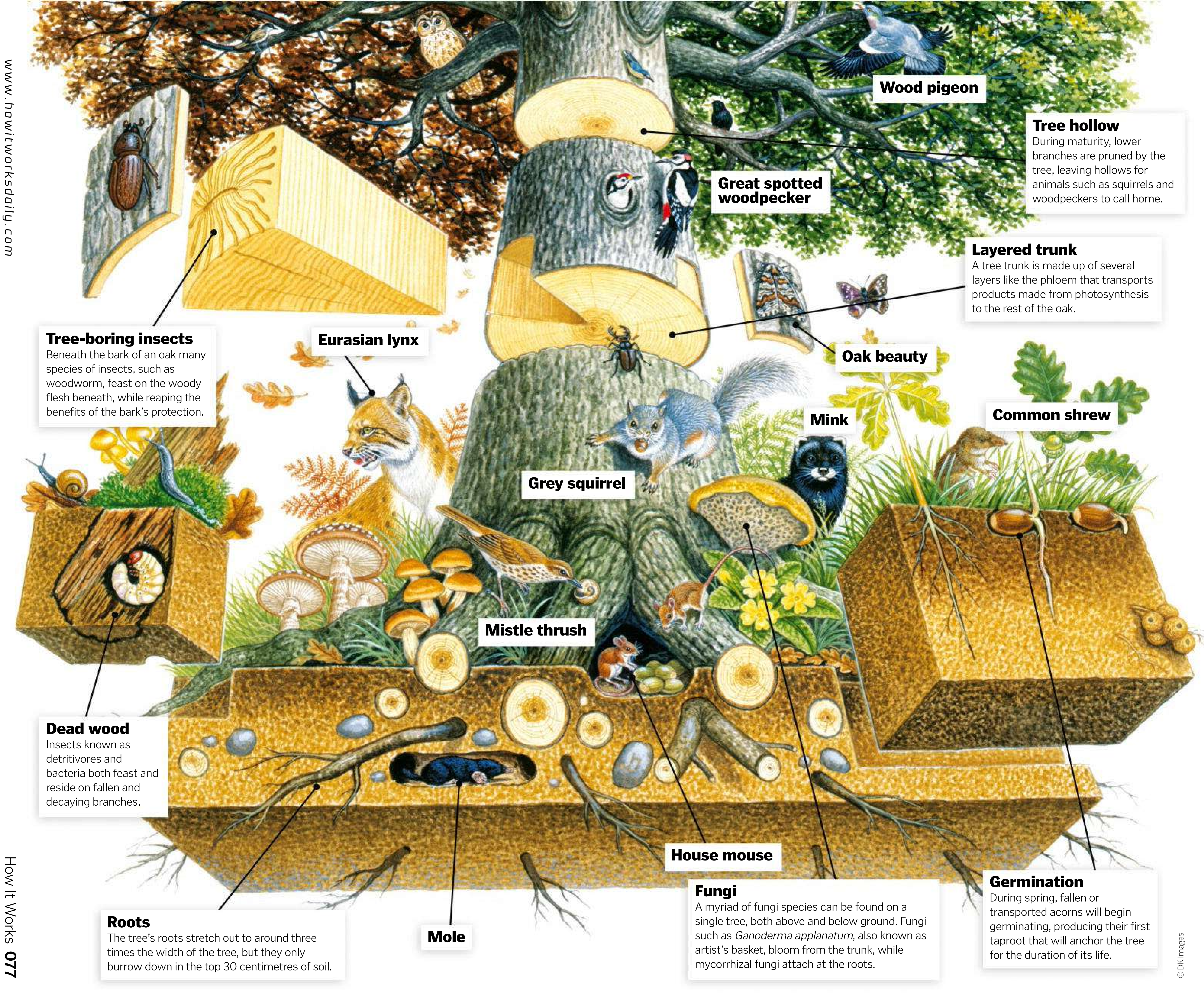
THE MIGHTY OAK

A single oak is brimming with biodiversity throughout the year





Tree hollow
During maturity, lower branches are pruned by the tree, leaving hollows for animals such as squirrels and woodpeckers to call home.

Layered trunk
A tree trunk is made up of several layers like the phloem that transports products made from photosynthesis to the rest of the oak.

Tree-boring insects
Beneath the bark of an oak many species of insects, such as woodworm, feast on the woody flesh beneath, while reaping the benefits of the bark's protection.

Dead wood
Insects known as detritivores and bacteria both feast and reside on fallen and decaying branches.

Roots
The tree's roots stretch out to around three times the width of the tree, but they only burrow down in the top 30 centimetres of soil.

Fungi
A myriad of fungi species can be found on a single tree, both above and below ground. Fungi such as *Ganoderma applanatum*, also known as artist's basket, bloom from the trunk, while mycorrhizal fungi attach at the roots.

Germination
During spring, fallen or transported acorns will begin germinating, producing their first taproot that will anchor the tree for the duration of its life.

How whale death equals new life

Most of the world's whales end up as food on the ocean floor

The body of a whale can support millions of deep sea organisms

On an average day, creatures living in the depths of the ocean rely on 'marine snow' – a slow trickle of nutrients from the surface. Every so often, however, a huge feast falls several kilometres through the water and comes to rest on the seabed. The enormous carcass of a whale supports a variety of creatures – from microbes to sharks – for decades, with every part ultimately consumed.

The first hint of the importance of whale falls came from a paper published in 1900, documenting the discovery of a small mussel clinging to a whalebone picked up by trawlermen. It wasn't until decades later that the first full skeleton was spotted by divers. At the time they described it as looking like the remains of a dinosaur, but it was soon identified as a whale, and bones were collected for research.

There are three successive stages in the whale fall ecosystem, each made up of a community making use of certain parts of the carcass. The stages can overlap as different creatures are drawn to the scent of the body, but the third and final stage is perhaps the most fascinating; it's the most diverse community known to exist on the seafloor.

The discovery of large numbers of fossilised clams around 30-million-year-old whale

Stages of whale decay

The end of a whale's life is the beginning of a whole new ocean community

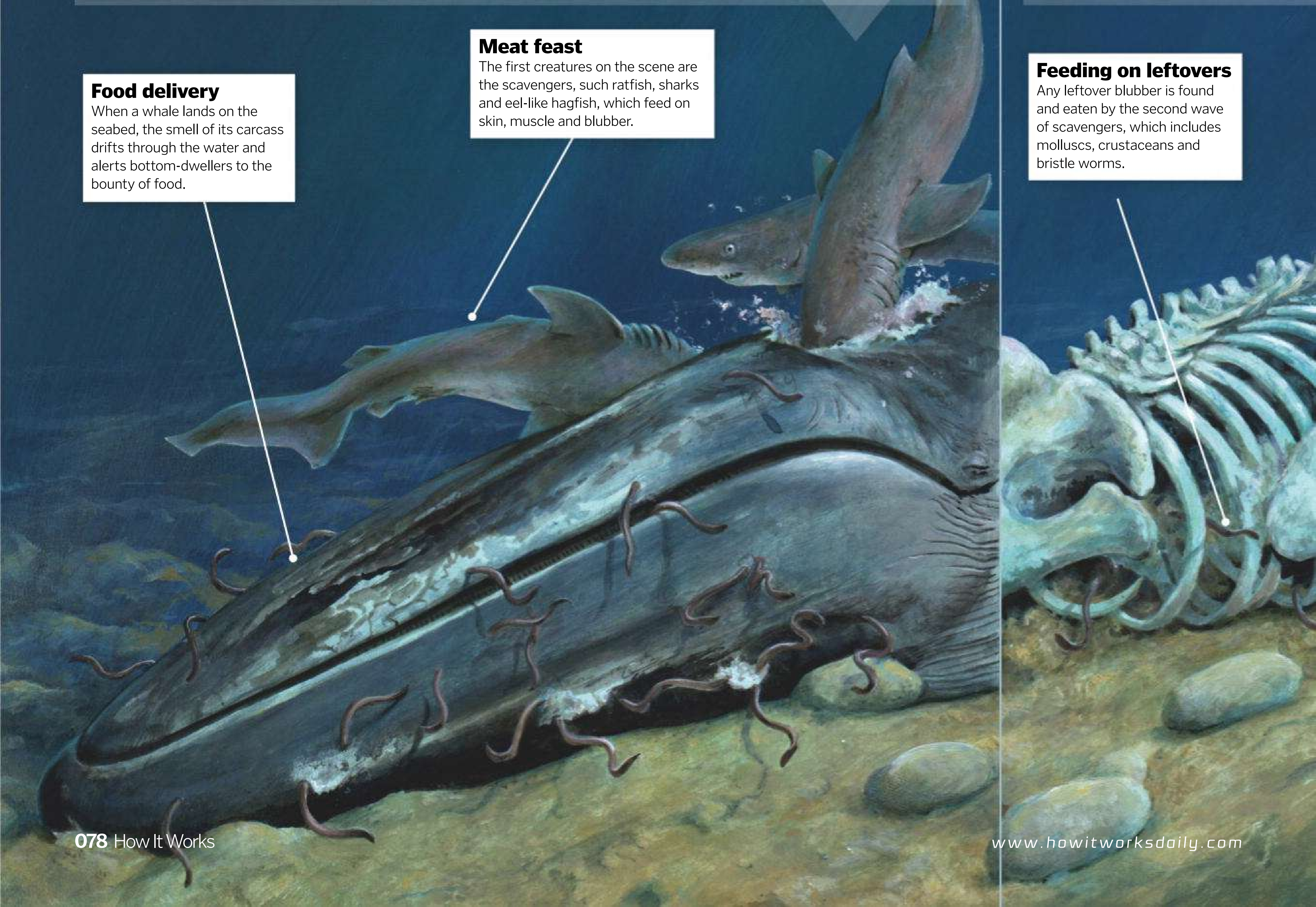
Scavenger stage DURATION: Up to 2 years

A newly fallen whale's soft tissues provide a couple of years' worth of food for larger scavenging creatures. As the scavengers chew on the meat they expose the inside of the carcass.

Opportunists arrive

DURATION: Up to 2 years

When the large animals have eaten



Hagfish, early scavengers to a whale fall, are the only known animals with skulls but no spines

bones suggests that whale fall ecosystems have existed for as long as there have been whales in the ocean. As many of the species found at whale falls are specially adapted to life on whale carcasses, they must travel from body to body as food runs out in order to survive. While humans rarely come across whale falls, experts believe they might occur as commonly as one every five kilometres off the coast of North America.

Finding whale falls

Whale falls are extremely valuable for marine biologists studying the diversity and ecology of life under the sea. The first was happened upon by chance in 1987, and since then only a few dozen natural whale falls have been found; often they land in water so deep they remain undiscovered by humans. Even with so few finds, scientists have already catalogued a multitude of previously unknown species in the busy communities around the carcasses.

Strandings on beaches provide scientists with an opportunity to study the decomposing bodies of these massive cetaceans and learn more about them. As natural whale falls are so hard to come by, they are sometimes created by sinking parts of stranded whales. These man-made falls offer additional glimpses into the process of decomposition and the creatures that feed on the remains.

Whales that wash up or become stranded are easier to study than those that sink to the seabed

their fill, smaller scavengers arrive to clear up what's left of the blubber and get to work on the other body parts.

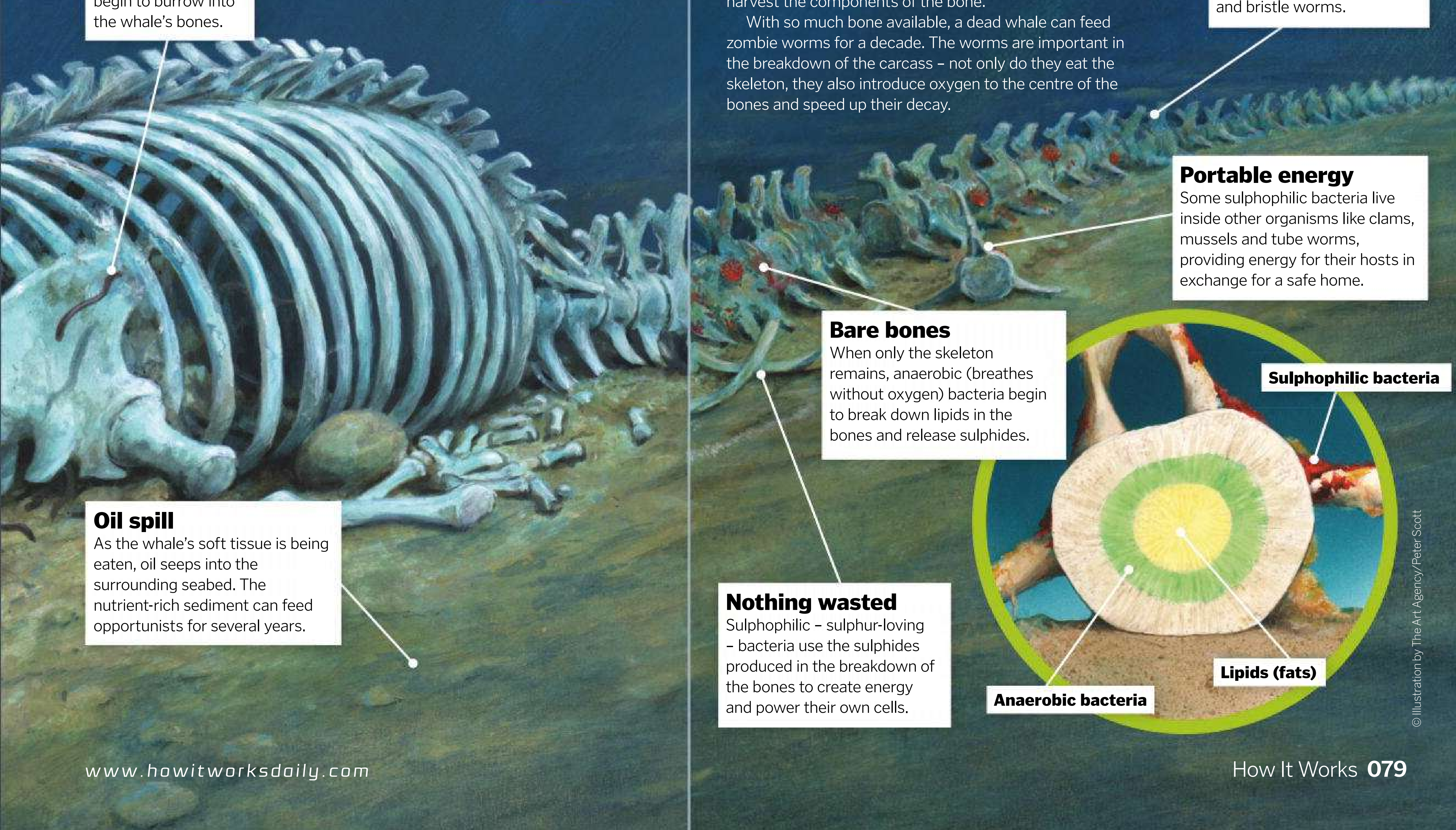
Time of the sulphur lovers DURATION: Up to 50 years

Anaerobic bacteria feeding on the remaining scraps produce the hydrogen sulphide needed by other bacteria, which in turn serve as food for larger organisms in a self-contained food web.

Bone-munching zombie worms

In 2002, scientists made a remarkable discovery – a genus of marine worms that devour the bones of dead whales. These invertebrates, known as zombie worms thanks to their gruesome lifestyle, play a crucial part in the decomposition of the carcasses. Boring into the skeleton, the worms produce enzymes and acids to break down and harvest the components of the bone.

With so much bone available, a dead whale can feed zombie worms for a decade. The worms are important in the breakdown of the carcass – not only do they eat the skeleton, they also introduce oxygen to the centre of the bones and speed up their decay.



Attack of the zombies
Once the skeleton is exposed, zombie worms move in and begin to burrow into the whale's bones.

Microscopic meal
Mats of sulphophilic bacteria living on the whale's skeleton are hoovered up by creatures such as limpets and bristle worms.

Portable energy
Some sulphophilic bacteria live inside other organisms like clams, mussels and tube worms, providing energy for their hosts in exchange for a safe home.

Bare bones
When only the skeleton remains, anaerobic (breathes without oxygen) bacteria begin to break down lipids in the bones and release sulphides.

Oil spill
As the whale's soft tissue is being eaten, oil seeps into the surrounding seabed. The nutrient-rich sediment can feed opportunists for several years.

Nothing wasted
Sulphophilic – sulphur-loving – bacteria use the sulphides produced in the breakdown of the bones to create energy and power their own cells.

Why limpets are underwater gardeners

They might appear lifeless and unimportant, but limpets play a big role in their ecosystem

'Limpet' is a term that's used to describe a variety of both freshwater and marine gastropods (kinds of slugs or snails). Many of these are only distantly related, with some using lungs and others relying on gills, but they all share a characteristic shell. These tough, conical-shaped shells are the key to the limpet's success.

'True limpets' are often found in rock pools in the intertidal zone – an area above the water at low tide and below the water at high tide. When the tide is out they clamp down onto the surface of rocks to avoid being eaten and to stop their soft bodies from drying out. When the water returns, though, they're highly active creatures. Using a simple nervous system they navigate the rocks in search of algae, which they scrape into their mouths using a ribbon-like tongue covered in rows of sharp, rasping teeth.

By grazing like this, limpets control the growth of algae in their habitat. Preventing the algae from taking over enables other marine and intertidal species to thrive, maintaining the health and balance of the ecosystem. In turn, the feeders become the food – despite their hard shells and strong muscles, limpets are never completely safe from the persistent hunting efforts of predators like crabs, fish, starfish and shore birds.

Humans have also historically collected limpets. They're not the easiest animals to harvest, but the bodies of limpets can be eaten and their shells turned into jewellery and art. Their usefulness to humans has resulted in the introduction and spread of species outside of their natural range.

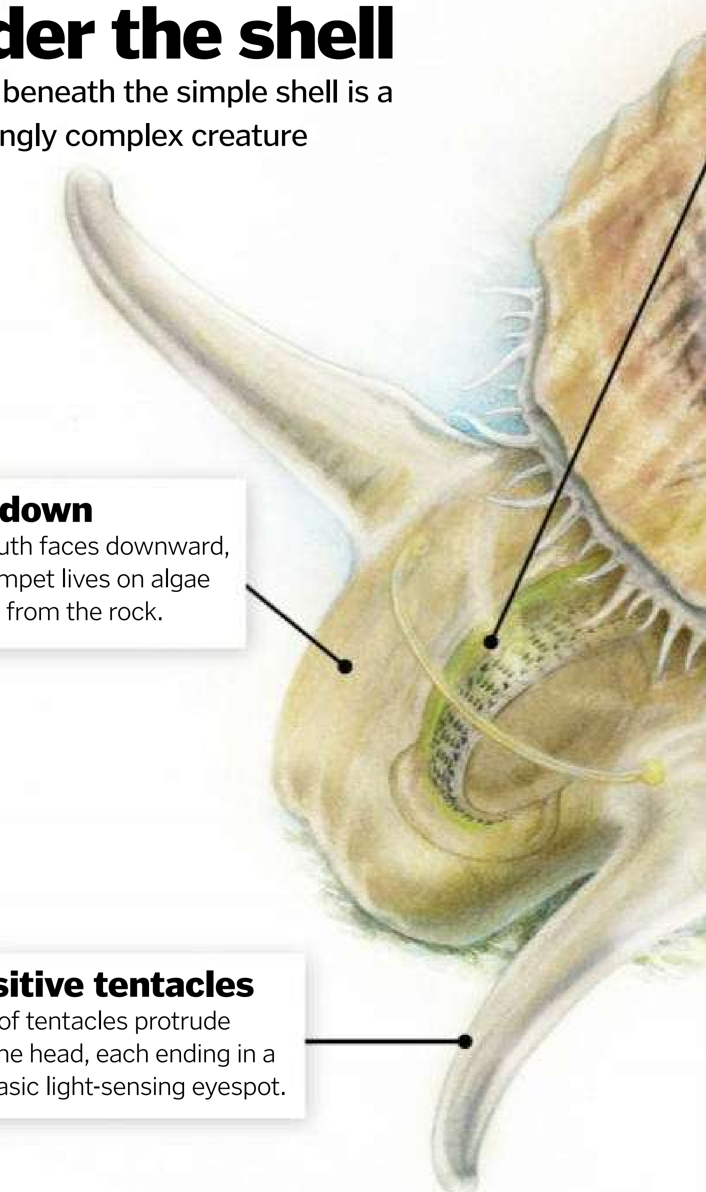
"Using a simple nervous system they navigate the rocks in search of algae"

Limpets' soft bodies make tasty meals for any animals that are able to peel them off the rock

Limpets cling tightly to rocks when the tide is out

Under the shell

Hidden beneath the simple shell is a surprisingly complex creature



Face down
The mouth faces downward, as the limpet lives on algae scraped from the rock.

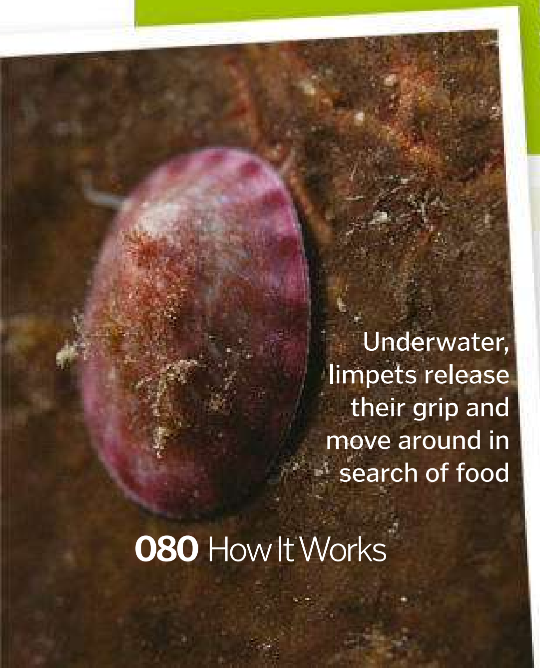
Sensitive tentacles
A pair of tentacles protrude from the head, each ending in a very basic light-sensing eyespot.

American invasion

Slipper limpets are native to the east coast of North America. The species was brought to Europe in the 19th century and is now a common sight on the southern coasts of England and Wales. Slipper limpets, named for their unusual shell shape, are versatile creatures able to survive in a range of different environments. With few predators in British waters the limpets are growing in number and spreading up both sides of the UK, although cold temperatures in the north may prevent them from invading along the full length of the coast.

Slipper limpets form mating stacks with large females at the bottom

© Shutterstock



Underwater, limpets release their grip and move around in search of food

From larva to limpet

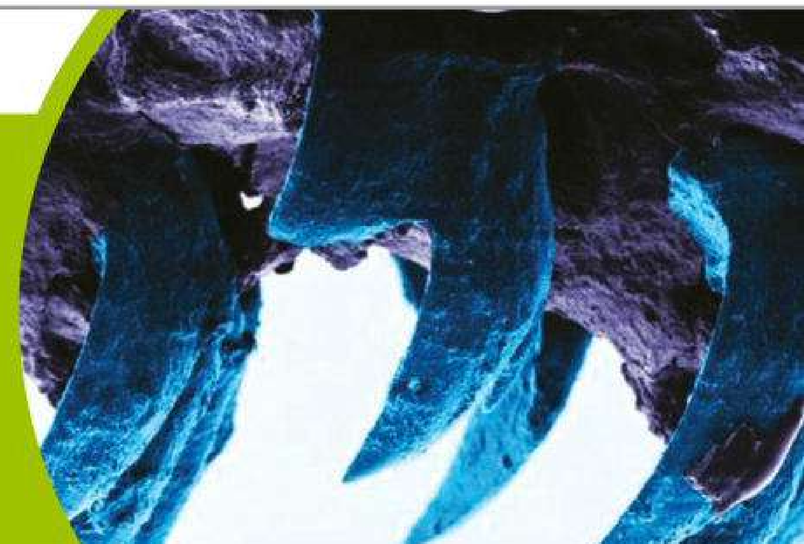
Young limpets undergo metamorphosis as they grow

Cleavage
Hours after fertilisation
Rough waters trigger the release and dispersal of sperm and egg cells, which meet and multiply to form embryos.

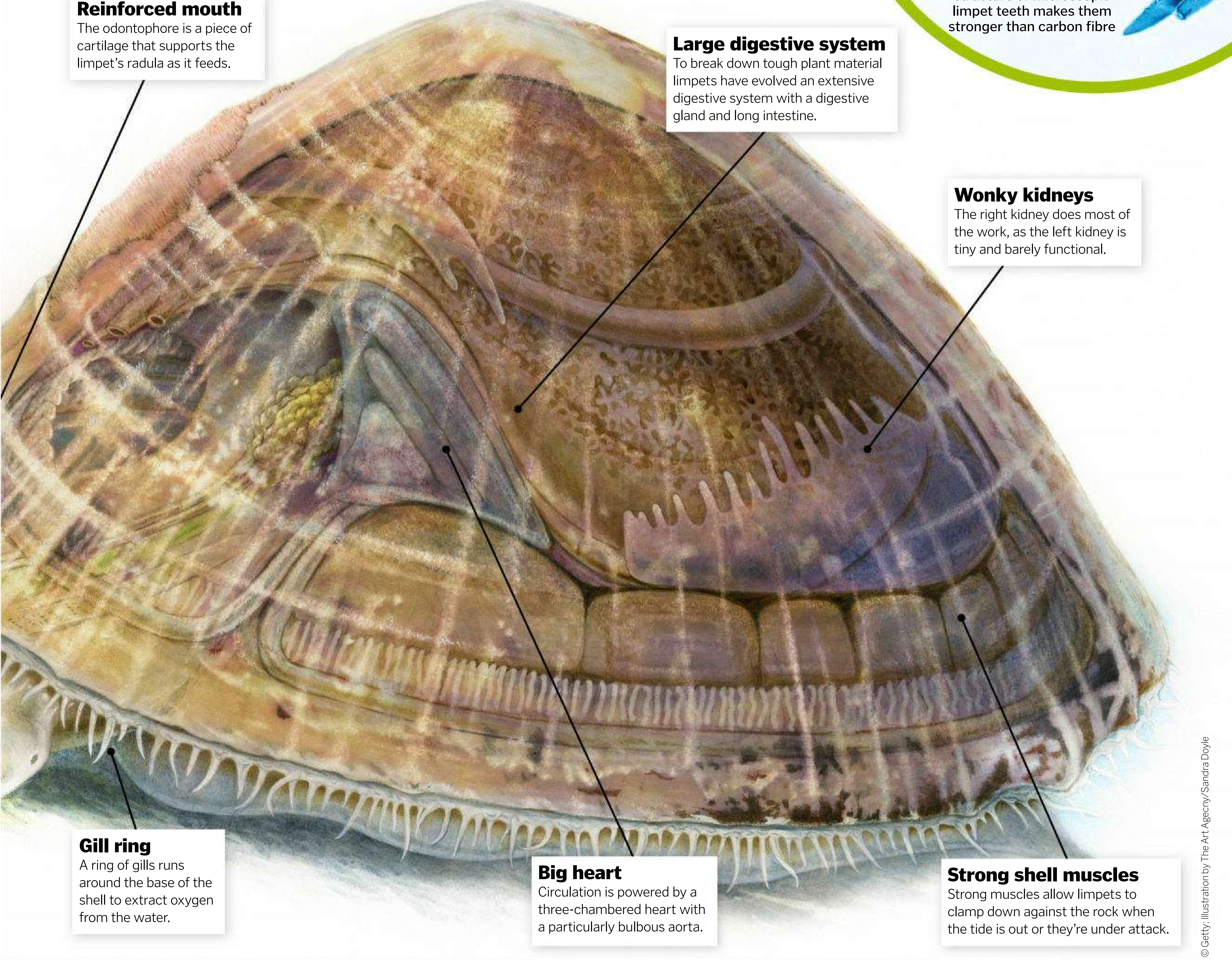
Trochophore
25 hours
Free-swimming trochophore larvae use cilia to sweep food into their mouths and fuel their growth and development.

Nature's strongest material

For many years spider silk was believed to be the strongest biological material in the world, but in 2015 the spider lost its title to a surprise competitor – the limpet. Scientists discovered that the composition and structure of a limpet tooth, which measures less than one millimetre in length, makes it around six times stronger than spider silk and ideal for rasping algae from rocks. Millions of nanofibres of a hard substance called goethite line up within a shell of chitin – the primary component of insect exoskeletons – making the teeth both tough and flexible. Limpet teeth were found to be stronger than not only spider silk but also almost all man-made materials, and their tightly packed fibrous structure could one day be copied for use in engineering and high-performance mechanics.



Researchers at the Royal Society discovered that the structure of microscopic limpet teeth makes them stronger than carbon fibre



Reinforced mouth
The odontophore is a piece of cartilage that supports the limpet's radula as it feeds.

Large digestive system
To break down tough plant material limpets have evolved an extensive digestive system with a digestive gland and long intestine.

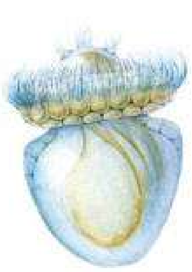
Wonky kidneys
The right kidney does most of the work, as the left kidney is tiny and barely functional.

Gill ring
A ring of gills runs around the base of the shell to extract oxygen from the water.

Big heart
Circulation is powered by a three-chambered heart with a particularly bulbous aorta.

Strong shell muscles
Strong muscles allow limpets to clamp down against the rock when the tide is out or they're under attack.

Early veliger
36 hours
Veliger larvae continue to swim in search of food using a pair of lobes known as the velum (meaning 'veil').



Mid-veliger
3 days
Towards the end of the veliger larval stage, limpets begin to develop a tiny shell.

Crawling larva
1 week
Eventually limpets stop swimming and sink to the sea floor, where they spend several weeks as crawling larvae.

Juvenile limpet
6 weeks
The larvae metamorphose into juveniles, miniature forms of the adults they'll grow into.

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Could we create certain elements in a human-made fusion reactor?

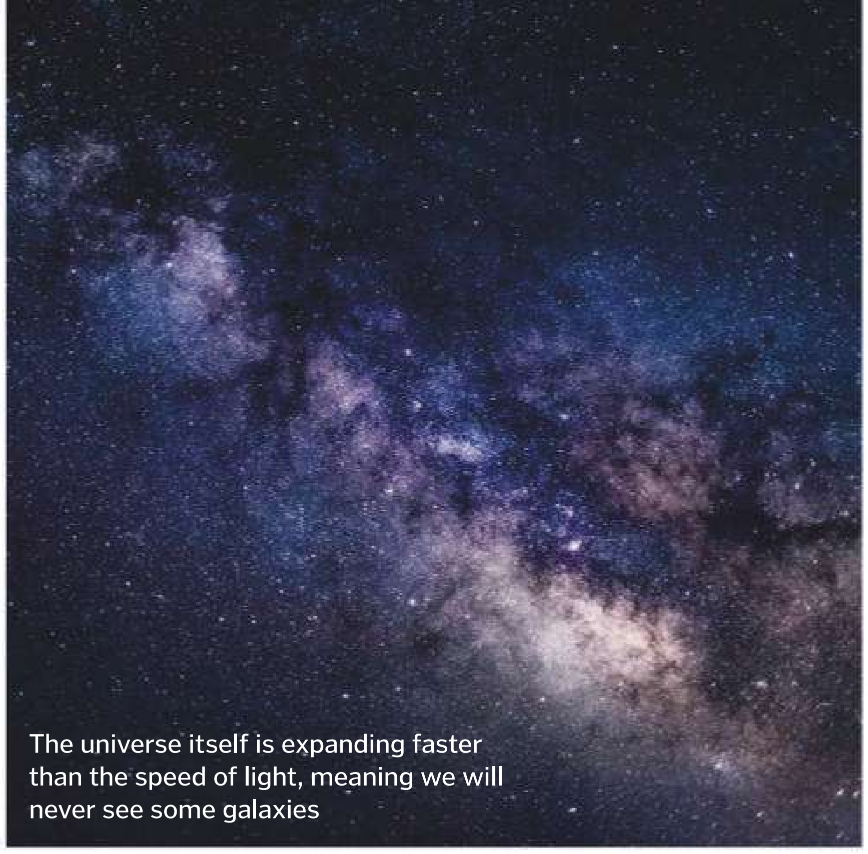
Lottie Ackerley

A fusion reactor could certainly make some interesting 'artificial' elements. The immense amount of energy and a hefty number of atomic collisions would temporarily produce very 'heavy' elements that would be too unstable to exist otherwise. **JH**

Can anything travel faster than light?

Mark Bryant

The speed of light has been described as the 'universal speed limit' of almost 300,000 kilometres per second. Nothing can move faster than light within a vacuum – that is, when moving through the expanse of the universe. But the universe itself is constantly expanding, pushing galaxies further from one another. As the universe is expanding into literally nothing, there's no limit as to how fast it can go, and so this can easily exceed the speed of light. **JH**



The universe itself is expanding faster than the speed of light, meaning we will never see some galaxies

Many evergreens have undergone key adaptations to help their leaves endure the prolonged cold

How do evergreen plants stay green all year round?

Stephanie Williams

Deciduous plants – those that lose their leaves – do so as a protection strategy during the winter months. With little light around and cold temperatures freezing and damaging cells, it's better for the plant to lose its leaves and regrow them in the spring. But evergreen plants, having often evolved in prolonged cold, have adapted to mitigate these issues. Coiling their leaves into fine needles and coating them in a waxy substance prevents moisture loss, and pooling sugars in their cells helps to prevent freezing by lowering the freezing point of water. By keeping their leaves all year round, evergreens can continuously collect energy from the Sun during photosynthesis and preserve nutrients that are held in their leaf cells. **JH**

Over time, babies can learn to love bitter-tasting food

Why do children tend to be such fussy eaters?

Joel Francis

Fussiness in childhood probably helped to keep our ancestors safe. You only have to look at the huge variety of foods consumed across the world to see how varied our diets can be. But this adaptability can be dangerous. If we were born willing to eat anything, we might accidentally eat something poisonous. Children tend to be particularly sensitive to bitter-tasting foods like sprouts and broccoli. This is because plant poisons often taste bitter. The way to overcome this aversion is to keep trying – over time, our bodies learn that bitter foods are safe, and they start to taste a bit better. **LM**

Can too much oxygen kill you?

Lou Donald

■ Yes. Oxygen can strip molecules in your body of electrons, creating free radicals. These react with other molecules to damage or kill cells. Our bodies keep this damage to a minimum using antioxidants, but can only do this for a typical amount of oxygen in the blood – a higher concentration will start causing damage. **JS**

The 'wings' of a boomerang are shaped in a similar way to airplane wings and create lift

Why does a boomerang come back?

Dan Ellis

■ When you throw a boomerang at just the right angle it has two different speeds as it travels through the air – a rotating speed and a forward speed – which causes it to spin. The wing at the top of the spin is both moving and rotating forward, meaning that it is going faster and generating more lift than the bottom wing. The unbalanced forces, called torque, causes the boomerang to tilt and travel in a circular path. **JS**

How do we know climate change is real?

Stephen Ellis

■ While Earth's climate has experienced cycles of warming and cooling throughout its history, the current rate of warming is happening at unprecedented speeds. By studying ice cores, tree rings, ocean sediments and layers of sedimentary rock, scientists can tell that the concentrations of greenhouses gases in the atmosphere now are higher than they have been for hundreds of thousands of years, and this is causing the planet to warm. The planet's average surface temperature has increased by 0.9 degrees Celsius since the late 19th century, leading ice sheets to melt, sea levels to rise and extreme weather events to become more common. **JS**

Global warming is extremely likely to be the result of human activity since the Industrial Revolution

Who created the first emoji?

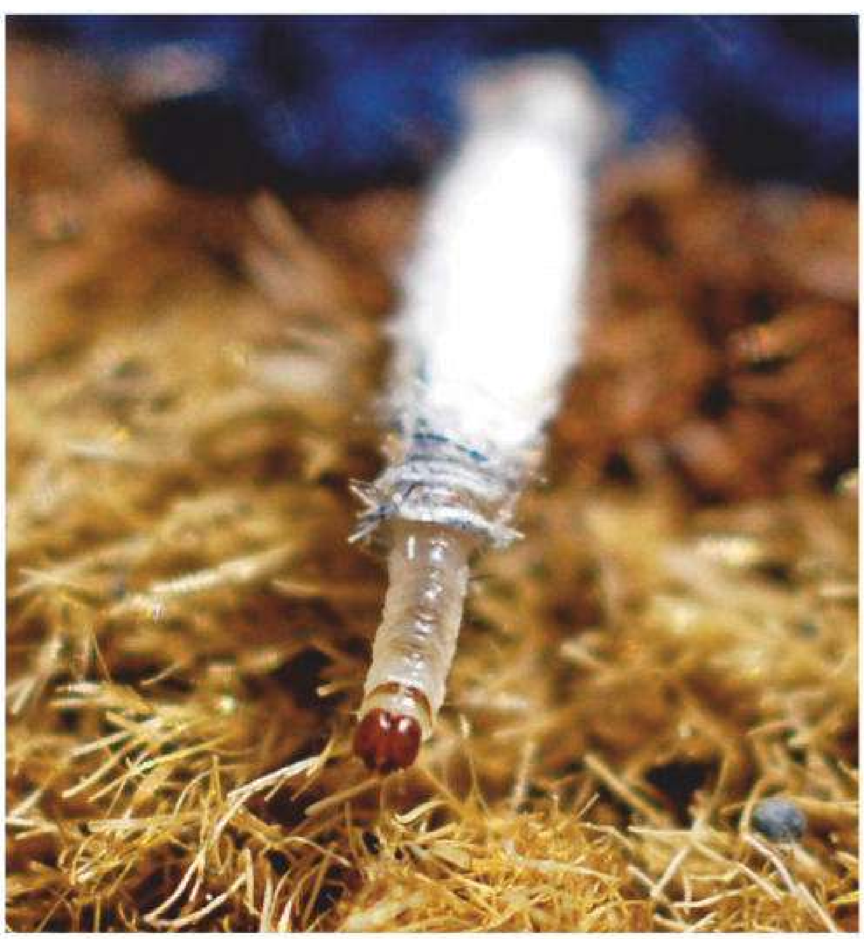
Sylvie Jarrett

■ Japanese artist Shigetaka Kurita created the first emojis in 1999 for phone company NTT Docomo. The original set included icons for weather, time and a heart – designed to make communication easier. **JT**

Why do moths eat clothes?

Noel Richards

■ Contrary to popular belief, adult moths don't eat your clothes, their larvae do. Female moths lay their eggs on clothing that her worm-like young will enjoy munching on, such as silk, wool and cashmere – anything made from natural fibres. These materials contain the protein keratin, which the larvae need in order to grow. **JT**

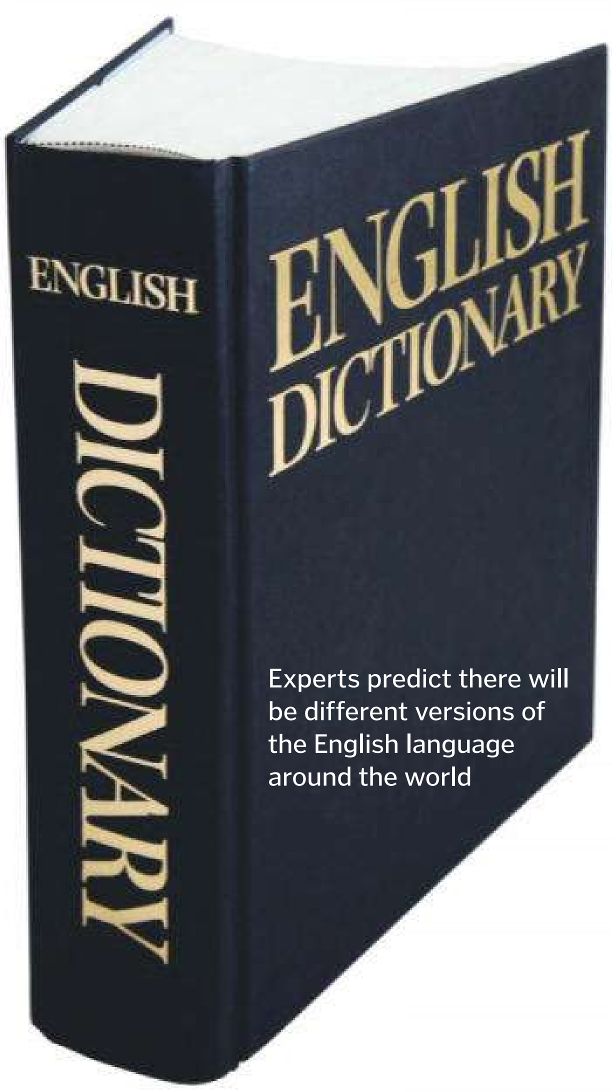


A headache is caused by pain-sensitive structures in the face or head, not the brain itself

What is a headache?

Frances Conn

■ When you experience a headache, it's not your brain hurting but the pain-sensitive structures like the muscles, membranes, veins and arteries that surround, and run through, the brain. If they become irritated, dehydrated or inflamed due to illness or not drinking enough water, for example, the brain will interpret this as pain in your head. The brain itself can't actually detect damage, which is why people can undergo brain surgery while awake. **JT**



Experts predict there will be different versions of the English language around the world

What will the English language be like in 100 years?

Richard Murray

■ By 2020, it's predicted that 2 billion people will be speaking English, but only 15 per cent will be native speakers. Some experts think this will lead to multiple versions of English as pronunciations become merged with other languages. This has already happened in parts of the US, where Spanglish (a hybrid of English and Spanish) has become common; and similarly with the spread of US English. It wouldn't be the first time this has happened. As the Roman Empire spread so did Latin, but with the fall of Rome, Latin eventually became French, Italian, Spanish, Romanian and Portuguese. **JT**

Can I burn calories just by thinking hard?

David Lees

■ Your brain is your most power-hungry organ, burning through around 20 per cent of your energy. But its power usage is fairly constant. Sadly, thinking hard won't help you burn extra calories. **LM**

Why are duck's feet orange?

Holly Grant

■ It's down to a combination of vitamins and hormones. Vitamin A and beta-carotene in the duck's diet provide the pigments to make the colour. Hormones intensify the orange during the breeding season, helping male ducks to show the females that they're well fed and ready to mate. **LM**

Can really hot chillies kill you?

Clive Mathers

■ It's possible. Chillies burn because they contain a molecule called capsaicin, which interacts with heat-sensitive nerve cells. It can cause numbness, pain, blistering, sweating and vomiting, and it can even trigger asthma attacks or anaphylactic shock. The hotter the chilli, the more extreme the response. Most of the time the effects are just unpleasant, but in one very unusual case a man retched so hard after eating puréed ghost pepper that he tore his oesophagus. **LM**

Ghost peppers are some of the hottest chillies in the world

Do tall people have more cells in their bodies?

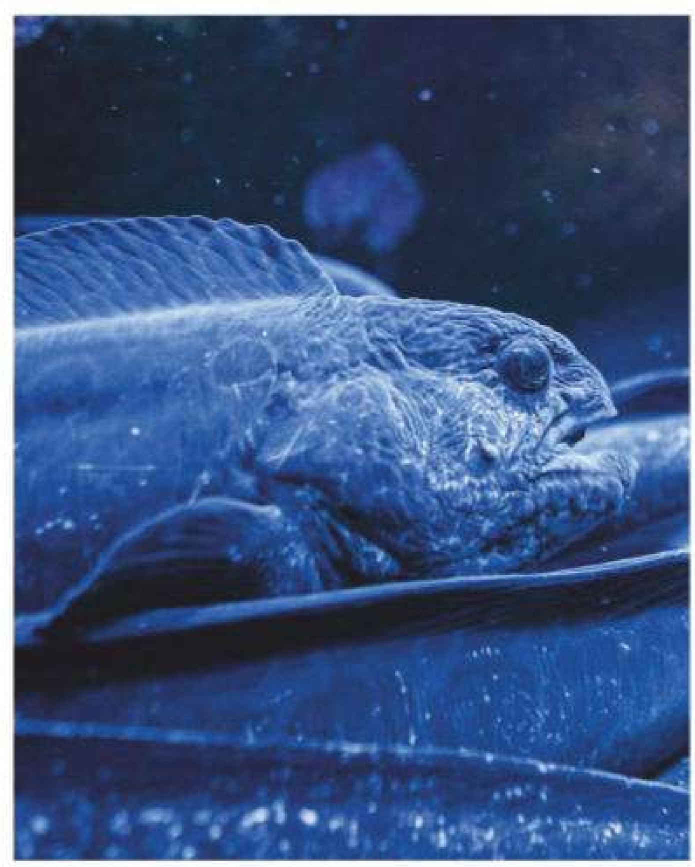
Clare Wallis

■ Yes they do, and research has even found that taller people are more prone to cancer because they have more cells, with the risk increasing by ten per cent per ten-centimetre increase in height. **JS**

Why don't electric eels electrocute themselves?

Laura Wells

■ Electric eels probably avoid electrocuting themselves because they are large compared to their electric shock's power, and the electricity-generating cells in their tails are far from the vital organs near their heads. **TL**



Want answers?

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Why are some meteor showers annual?

Peter Sykes

A meteor shower happens when the Earth travels through the trail of debris left behind by a comet passing through the Solar System. It takes the Earth a year to orbit the Sun, so each year the Earth passes through the same debris trail around the same date, causing an annual meteor shower. **TL**

Scientists are constantly helping to improve the treatment of cancer

How close are scientists to finding a cure for cancer?

Nicholas Wicke

Some cancers can be cured if they are treated early enough. However, although improvements are always being made, it is unlikely there will be one universal cancer cure. Cancer is actually many different diseases and affects people differently. This makes it more likely that the key to curing cancer will be the design of personalised programmes of chemotherapy, drugs, surgery, radiotherapy and other treatments for individual people and their particular cancer, rather than a universal cure. **TL**

What does a star sound like?

Verity Dee

Sound waves travel through the body of stars as hot gases move inside them. However, as sound can't travel through the vacuum of space, we can't actually hear stars, but we can listen to them in other ways. Scientists using telescopes have been able to observe disturbances in the light of stars, caused by waves moving through them, and convert this into sound we can hear. Stars also produce electromagnetic radiation that we can pick up with radio telescopes and listen to them like radio stations. In fact, through radio telescopes, some stars sound like badly tuned radios, while others make repetitive clicks or beeps. **TL**

Using radio telescopes scientists can hear the electromagnetic signals generated by stars

BOOK REVIEWS

The latest releases for curious minds

The Encyclopedia of Dinosaurs: The Theropods

Everything you could ever want to know about dinosaurs

■ Author: **Rubén Molina-Pérez and Asier Larramendi** ■ Publisher: **The Natural History Museum**
■ Price: **£30 (approx $38)** ■ Release: **Out now**

Who doesn't like dinosaurs? Whether you love the idea of finding out more about the prehistoric animals that lived hundreds of millions of years before us, or just enjoy watching the spectacle of *Jurassic Park*, there are few creatures that can match dinosaurs for excitement and interest. And while scientists are still discovering new species, this encyclopedia from the Natural History Museum aims to bring together all the latest information about the theropods – those classified as having 'beast feet' – into one place.

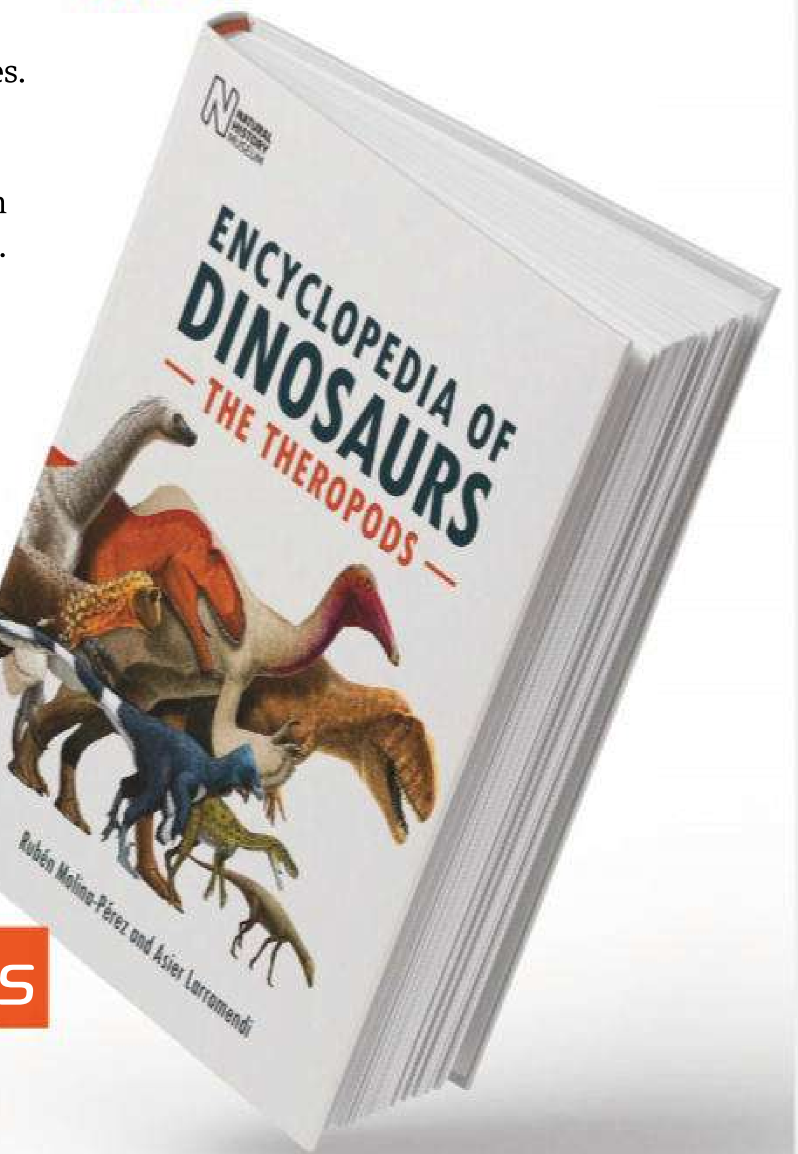
The theropods form one of the three great dinosaur groups; it's the most diverse and contains the most recognisable species. Whether it's the seven-ton Spinosaurus, the tiny Microraptor or the world-famous *Tyrannosaurus rex*, you're sure to find a creature in here to spark your imagination.

The book is split into eight sections, each exploring a different area of the various species. You'll learn about the largest and smallest specimen in each taxonomic group, see an impression of their footprint, find out where in the world they could be found and much more. Throughout the encyclopedia you'll find excellent illustrations that give readers an idea of how each species might have looked. And because the book contains information discovered right up until 2016, you'll find a number of feathered creatures within the pages, based on the most recent research and discoveries.

While reading, it quickly becomes clear that this is a book written by, and most likely for, academics. This is no bad thing – as the authors themselves say early on, such an up-to-date, detailed book has never been created before, so making such a comprehensive compendium is a worthwhile endeavour.

However, more casual readers may find that the language used here lacks the flair to keep them interested. Useful reference points for size and weight will help readers understand the creatures in real terms, and a section at the back is packed with more light-hearted, engaging facts about dinosaurs in culture. But sprinkling these references throughout the book could have livened it all up and made this something for all kinds of readers – not just those with a serious passion for the prehistoric creatures.

Still, if you want to know everything about the largest and smallest of the theropods, this is the book for you.



"Few creatures can match dinosaurs for excitement"

50 Things to See in the Sky

Visions of wonder

■ Author: **Sarah Barker**
■ Publisher: **Pavilion**
■ Price: **£9.99 / $16.95**
■ Release: **Out now (UK) / 1 October (US)**

The activity of stargazing has been experiencing a resurgence in popularity of late, and it's easy to see why. With a practised eye, the known universe is right there before your eyes.

If this is something you'd like to experience for yourself but are unsure what to look for, consider this book your entry point. Put together by astrophysicist, science writer and producer Sarah Barker, with able assistance from illustrator Maria Nilsson, contained within are 50 things that are possible to view with the aid of a telescope, and is rather fittingly published half a century after the Moon landings.

From the Milky Way and the Moon itself to more distant phenomena like 'failed stars' and a baby solar system, we're considering making this our space bible. The how-to guides are brief but perfectly succinct, arming you with both the knowledge of what you are looking at and the know-how of how to get that. Nilsson's artistry shouldn't go unmentioned either, her monochrome drawings providing an aptly minimalist accompaniment to Barker's words.

Bitesized in format yet nourishing with every morsel, beginner and experienced astronomers alike could do little wrong by picking this up.

Science You Can Eat

Bitesized bravado

- Author: **Stefan Gates**
- Publisher: **DK Children**
- Price: **£12.99 / $16.99**
- Release: **Out now**

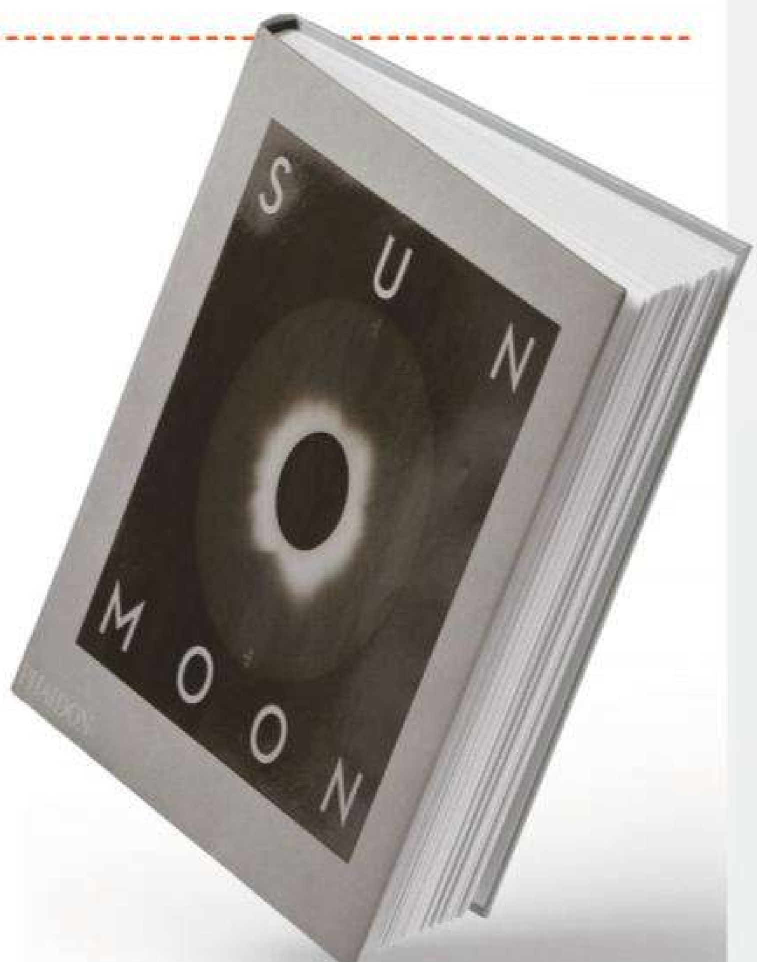
What makes bread rise? Why do onions make us cry? Why does popcorn pop? All this and other kitchen conundrums are explored in this latest kid-friendly offering from DK, which takes us through the scientific secrets of our favourite foods – or rather, our children's favourites.

Starting with a rank-and-file description of the functions of the senses, pretty much every page is filled with the kind of information that you're sure to hear your kids parrot back at you at some point – did you know that ice cream is a result of 'colloidal emulsion'? You do now. Plus there's the seemingly obligatory slime section to sink your teeth into.

Our only criticism is that the cover doesn't make it fully clear exactly what this will be about – it's a guide to food rather than a complete scientific breakdown of what it all entails. But this is a minor gripe; overall this is yet another solid offering from DK and one that will keep the children entertained for hours.

Sun and Moon

Through the looking glass



- Author: **Mark Holborn**
- Publisher: **Phaidon Press**
- Price: **£59.95 / $79.95**
- Release: **Out now**

We love a good coffee table read, but they're one hell of a commitment – our busted shoulder stands as testament to the mission it was to lug this tome back home. But does *Sun and Moon* – another book commemorating the 50th anniversary of the Moon landings – justify the inadvertent workout that constituted getting it?

Ultimately it'll depend on what you're hoping to get out of it. Starting out with early Neolithic observatories before progressing through early star charts and formative attempts at creating telescopes, what would usually form the introduction to most books about space instead takes up a large proportion of this volume. It's well after halfway through proceedings before we get to the photos of space itself. Everything that comes before is undeniably interesting, giving us the lowdown on exactly how far we've come, but readers are entitled to feel a sense of mismatched expectations considering the overly space-heavy emphasis of the cover.

Moreover, at only a few pence short of £60, this is a commitment in more ways than one. While Mark Holborn's insight is as much of a reason to buy this as the blown-up images that form the book, this is probably an offering that's for space obsessives only.

Hawking: The Man, the Genius, and the Theory of Everything

A brief history of Hawking

- Author: **Joel Levy**
- Publisher: **Andre Deutsch**
- Price: **£20 / $29.95**
- Release: **Out now**

In the wake of his death, there have been numerous book-bound chronicles depicting his life and the indelible mark it left on life, the universe and everything. This offering is at the more accessible end of the spectrum: for those who want to gain an understanding of what Stephen Hawking achieved but are a tad intimidated by *A Brief History of Time*.

Chronicling his life, from his studies at Oxford and ALS diagnosis all the way through to the pioneering discoveries that would cement his place in history, this is a wide-ranging if curtailed account of his achievements. There's nothing in the way of interview access, so we'll have to rely on the author's judgement, but the quality of the writing and research is such that we have little reason to doubt him.

An abbreviated account of Stephen Hawking's legacy, perhaps, but all in all this is not a bad place to start.

BRAIN GYM

GIVE YOUR BRAIN A PUZZLE WORKOUT

Wordsearch

L	W	G	D	D	R	T	E	P	M	I	L	Q	X	A
X	E	X	P	S	F	C	O	S	M	I	C	M	V	T
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Z	P	F	O	T	L	K	E	E	N	Y	C	X	G	X
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U	X	E	L	E	M	E	N	T	E	X	V	Z	V	X
A	T	T	E	N	B	O	R	O	U	G	H	F	H	J

FIND THE FOLLOWING WORDS...

ATLASAURUS
ELEMENT
VACCINATION
LEONARDO
PENA
MOVIES
DATA
HYPERSONIC
VOYAGER
ATTENBOROUGH
COSMIC
HOPPER
TREE
WHALE
LIMPET

Quickfire questions

Q1 How fast could *Ornithomimus edmontonicus* run?
- 200kph
- 23kph
- 72kph
- 40kph

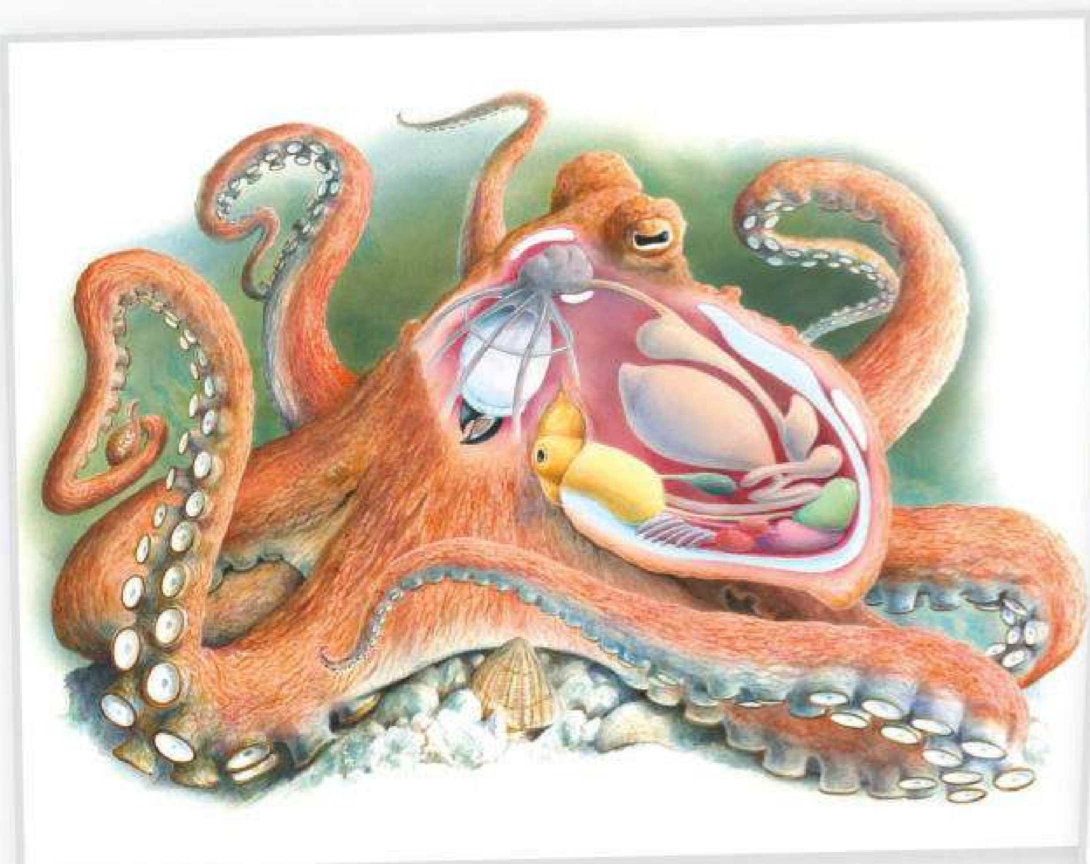
Q2 What is at the centre of an atom?
- An electron
- A nucleus
- An element
- A compound

Q3 How old is the universe?
- 4.2 billion years
- 42 million years
- 12,000 years
- 13.8 billion years

Q4 What percentage of Earth's land is covered by trees?
- 31 per cent
- 10 per cent
- 8 per cent
- 50 per cent

Spot the difference

See if you can find all six changes we've made to the image on the right



Sudoku

Complete the grid so that each row, column and 3x3 box contains the numbers 1 to 9

EASY

2		3		5	8	7	9	4
			9		3			6
9		5	6	7				3
	5		3	6	2	9		1
1	7	2	4	9		3		
	3		8	1	7	4	5	
8	1	7		3	9	6		
		6	7	4		8		9
3	9	4	5	8		2		

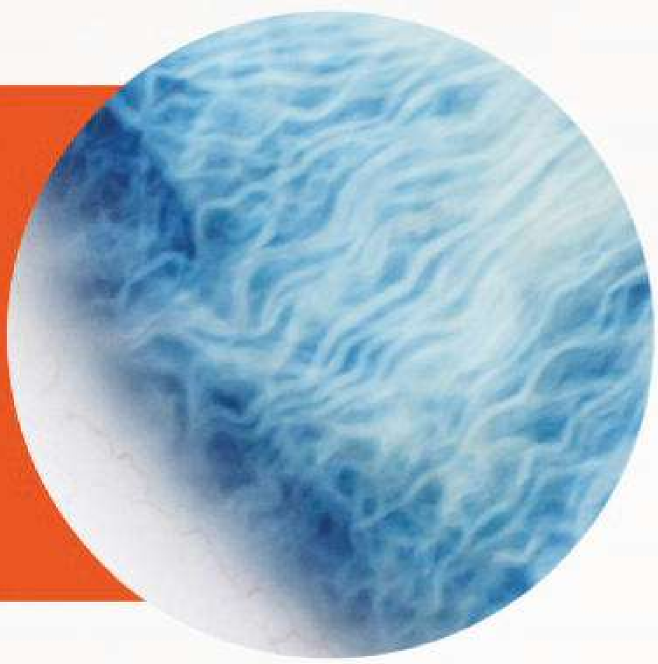
DIFFICULT

	7				5		2	
				6	1			4
2				4				
1				3				
5							3	
6	9		5			8		7
			7			5	9	
			8					
4		6		9		7	8	

What is it?

Hint: Focus hard on this image to see what it is. You're using it right now…

A ....



Spot the difference

Check your answers

Find the solutions to last issue's puzzle pages

Quickfire questions

Q1 Gravity

Q2 Elephant

Q3 A lunar mission

Q4 640 light years

What was it?

Cork

HOW TO...

Practical projects to try at home

DON'T DO IT ALONE
IF YOU'RE UNDER 18, MAKE SURE YOU HAVE AN ADULT WITH YOU

NEXT ISSUE
Discover how to make a rainbow

Make instant ice

Amaze your friends by turning liquid water into ice – instantly!

1 Chill your water

First, place two 1-litre bottles of deionised water in a deep bowl or bucket, and pack it with around 3kg of ice. You can also use filtered water, but deionised water for car batteries works best.

2 Add some salt

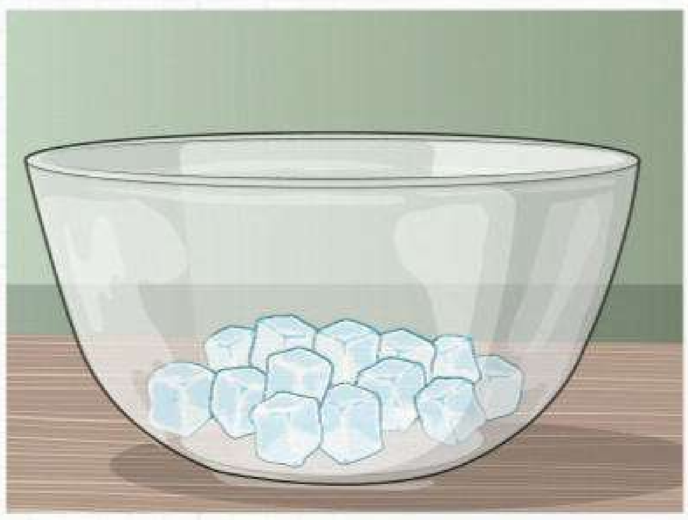
Pour 1.5kg of salt onto the ice. Top it up with water until the bottle's necks are submerged. The salt in the water upsets the dynamic equilibrium, and the water cools below 0° C to compensate.

3 Let it cool

Use a thermometer to check the temperature in the bucket. You're aiming for the bottles to reach around -8°C . Be careful not to disturb the bottles, as it may start the reaction.

4 Remove the bottles

Once they're at -8°C, very carefully remove the bottles and gently place them down. Check they're still liquid inside. If you knock them too hard, they may start to turn to ice, so take care!



5 Get more ice

Place a few ice cubes into a bowl. These should kick-start the reaction – before you pour the water it should stay as a liquid, but once it hits the ice cubes, it'll start freezing instantly.

6 Pour it out

Carefully unscrew the top of the bottle and start pouring it onto the ice. As it touches the ice, it will kick-start the crystallisation process, and an ice tower will start to grow as you pour.

7 Slam the bottle

Keep the second bottle sealed. Lift and slam it on the table. This will also start the crystallisation process, and will spread through the bottle.

SUMMARY...

Water usually freezes at 0°C, but only if there are impurities in the water, which act as a 'nucleus' that the crystals can form around. You can cool pure water below 0°C, as long as there is no nucleus. In this experiment, the ice cubes and the bubbles that appear as you slam the bottle act as the nucleus, and crystallisation begins!

Get in touch

HAD A GO? LET US KNOW! If you've tried out any of our experiments, conducted some of your own or have ideas for us to try – let us know! Share your photos or videos with us on social media.

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Our brains are able to create mental images by accessing our stored visual memories

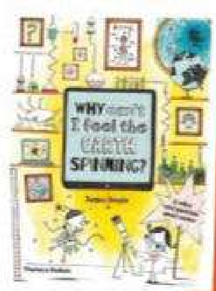
Letter of the month

Mind's eye vision

Hi **HIW**,

When we read a book and imagine the setting, for example, what is it we see that has been imagined, and how do we see it? I hope you can answer this question. Many thanks.

James Sainsbury



WIN!
WHY CAN'T I FEEL THE EARTH SPINNING?
Discover more about the world around you and get the answers to some of science's most fundamental and vital questions

That's a great question James! A well-written and descriptive book is a great way to gaze through your 'mind's eye' and imagine a world that you are reading. Technically known as mental imagery, our brains have the ability to translate the words from the page and generate a recognisable image in our heads.

The brain's ability to do this could be linked to the way we optically see, combined with our stored memories. Our memories are kept in biological files in several parts of the brain, particularly the hippocampus, and we process visual imaginary in the occipital lobe, which is located in the visual cortex. These combining abilities are thought to be the explanation and creation of our mind's eye.

To put it simply, when we view an image in real life, neurons fire in our brains, forming connections that will relate to that image for future use. By taking inspiration from the neurological information of our stored memories, our brains can stitch together an image of what we are reading.

However, if we have no reference images stored then that image can be different to generate. For example, if you've never seen an image of a desert before, when you read a book detailing the rolling dunes of the Sahara your brain wouldn't have any reference images to use to create that scene in your mind's eye.

Although we are creating a mental image when reading a book, the resulting scene has been dictated by the words we're reading. This process is different from our brain's ability to generate a new idea or image through imagination, without being prompted by text.

Echolocation explained

Hi **HIW**,

What is echolocation and which animals have it?

Isabel Daniells

Echolocation is a fascinating ability many species have evolved to depend on for everyday tasks, such as searching for food or navigating underwater. Animals that can echolocate emit a sound wave into the air or water and wait to hear the echoes to return to them. This can estimate the distance from objects or locate prey.

Many species use this technique, including bats, dolphins, whales and even humans. People with a visual impairment have been known to use echolocation. Making loud clicking sounds with their tongue, some people are able to listen for the returning sound waves and determine their position relative to possible obstacles.

Echolocation uses the echoes of emitted sound to perceive distance and locate prey

Denim

Hi **HIW**,

I was wondering if you could explain what is denim and why is it different from other fabrics used to make clothes?

Albert Foley

Denim is a common occurrence in anyone's wardrobe. The material used to make denim is cotton, although in items like jeans this can differ between manufacturers as a cotton blend.

What makes denim so unique is the way in which cotton threads are woven together to create the fabric. Horizontal weft threads, cotton woven in and out of the spaces between vertically strung threads called warp threads, pass under two or more warp threads, giving them their diagonal ribbing.

Braking power

Hi **HIW**,

Electric cars are becoming a lot more popular. They have different brakes to normal cars to help to boost their range. I was wondering how do regenerative brakes work?

Leo Stuart

During braking in non-electric cars, the kinetic energy is wasted and absorbed by the vehicle's physical brakes. Electric cars use regenerative braking or 'regen' to not only prevent this energy waste but store it for future use in the form of electricity. The electric motor, while braking, is electronically placed in reverse, turning backwards and slowing the car down. The motor acts as a generator utilising the kinetic energy and sending it to the car's battery as electricity.

© Getty

Regenerative braking converts wasted kinetic energy into electricity for future power use

There are over 4,000 different species of songbird all over the globe

© Getty

Songs of praise

Hi **HIW**,

It is good to see your article on 'Why Birds Sing'. However the main reason birds sing, surely, is because they are happy and bubbling over with sheer joy. They are glad to be alive and they want every other creature on Earth to know it. I have watched most of David Attenborough's DVDs and many times he ascribes animal behaviour to enabling the successful passing on of their genes. I am surprised that I have never once seen him refer to animal behaviour as displaying pure enjoyment or ecstasy.

Stephen Conn

What's happening on... social media?

This month, we asked you to tell us your favourite dinosaurs

@RB_C2

"Mine's a diplodocus. They are believed to have not been very clever, and they are the longest dinosaur! They had 100 vertebrae from their neck to tails!"

@lotpot3

"Velociraptor - even though they were fairly small in comparison to other dinosaurs they were agile and skilled predators."

@gottobein

"Leaellynasaura - love its large eyes"

@ho_jo86

"Triceratops - I've always loved the three-horned dino, I love its crown-like head, when I saw it in picture books, some were coloured blue and yellow and the one on Jurassic park looked incredible (albeit a bit under the weather). "

@angep1969

"Apatosaurus - such a gentle giant :)"

@susiedarlo

"I love T-Rex, big and strong and terrifying, however, I would not like to bump into one LOL"

NEXT ISSUE...

Issue 127 on sale 11 JULY 2019

Available in print from all good newsagents and **myfavouritemagazines.co.uk**, or as a digital edition for iOS and Android. To enjoy savings on the RRP and to make sure you never miss an issue, check out our subscription offers on pages 30 (UK) and 83 (US).

HOW IT WORKS

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Printed by William Gibbons & Sons Limited, 26 Planetary Road, Willenhall, Wolverhampton, West Midlands, WV13 3XB

Distributed by Marketforce, 5 Churchill Place, Canary Wharf, London, E14 5HU www.marketforce.co.uk Tel: 0203 787 9001

ISSN 2041-7322

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FAST FACTS

Amazing trivia to blow your mind

THERE ARE MORE ATOMS IN YOUR BODY THAN SECONDS IN THE HISTORY OF THE UNIVERSE

925KPH

AVERAGE CRUISING SPEED OF A PASSENGER JET

16,000

AROUND 25 PER CENT OF TREE SPECIES ARE FOUND IN THE AMAZON RAINFOREST

$115.5 MILLION

COST OF A SINGLE F35B LIGHTNING II FIGHTER JET

70%

THE PERCENTAGE OF THE UNIVERSE THAT IS DARK ENERGY

1980

THE DATE SMALLPOX WAS OFFICIALLY ELIMINATED BY VACCINATIONS

156

VFX STAFF EMPLOYED IN A TYPICAL 500-PERSON CREW HOLLYWOOD FILM

LIMPETS ARE TERRITORIAL AND SOMETIMES FIGHT OTHERS IN THE SAME ROCKPOOL

8,000 metres

THE DEPTH OF THE DEEPEST SUBMARINE COMMUNICATIONS CABLE

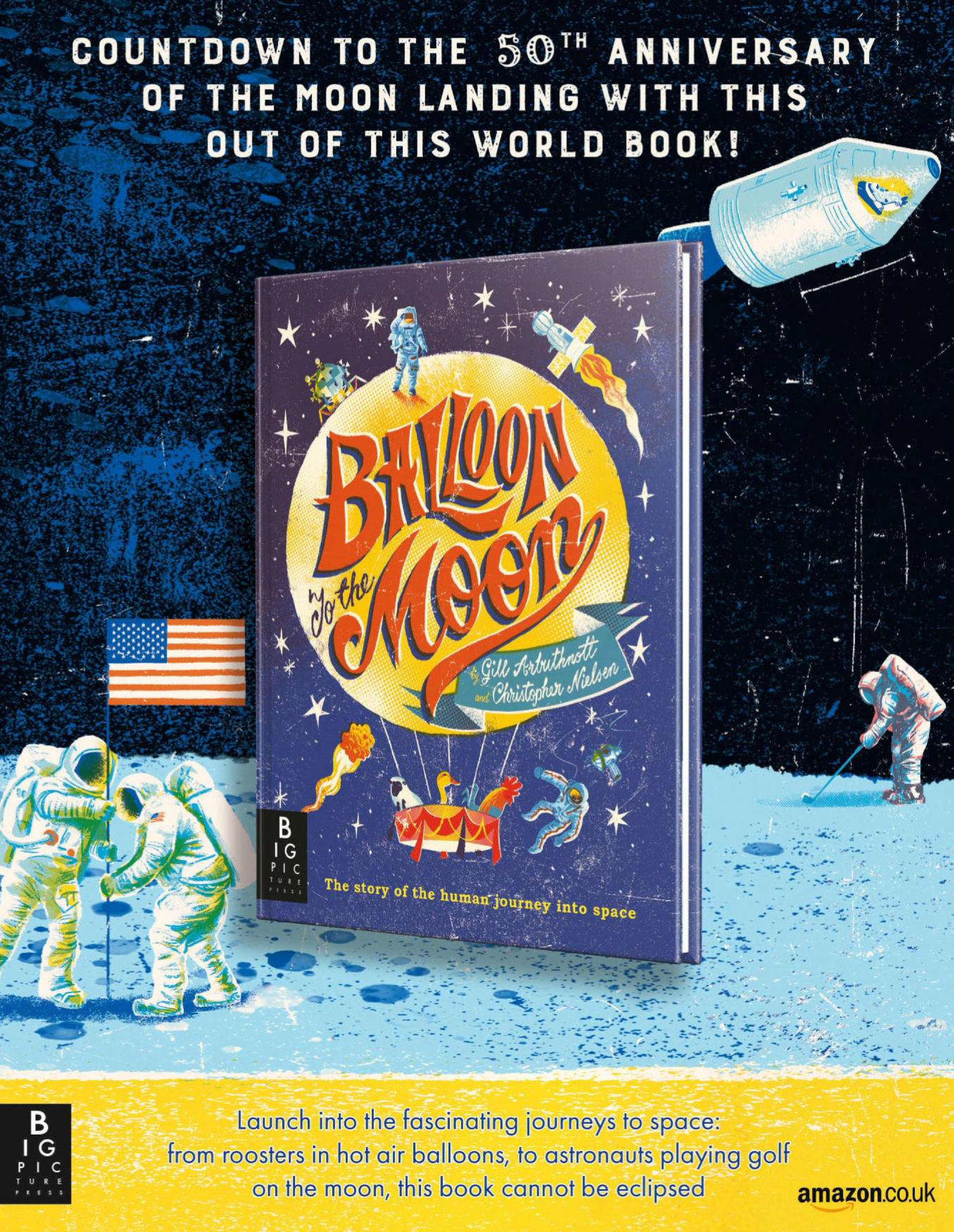
OVIRAPTORS WERE CARING PARENTS TO THEIR OFFSPRING

15TH

THE CENTURY THE FIRST TANK WAS INVENTED – BY LEONARDO DA VINCI

0

NO EVIDENCE OF A VENOMOUS DINOSAUR HAS EVER BEEN FOUND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